INDOOR AIR QUALITY - SYMPOSIUM PROCEEDINGS

Alberta
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Innovative Housing Grants Program

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INDOOR AIR QUALITY - SYMPOSIUM PROCEEDINGS

(Proceedings of a Symposium on Indoor Air Quality)

(Held at the University of Calgary, March 12-14, 1985)

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The views and conclusions expressed and the recommendations made in this report are entirely those of the authors and should not be construed as expressing the opinions of Alberta Municipal Affairs.

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FOREWORD

The project documented in this report received funding under the Innovative Housing Grants Program of the Alberta Department of Housing. In May, 1986 the Alberta Department of Housing was amalgamated with Alberta Municipal Affairs which is now responsible for issuing this report.

The Innovative Housing Grants Program is intended to encourage and assist housing research and development which will reduce housing costs, improve the quality and performance of dwelling units and subdivisions, or increase the long term viability and competitiveness of Alberta's housing industry.

The Program offers assistance to builders, developers, consulting firms, professionals, industry groups, building products manufacturers, municipal governments, educational institutions, non-profit groups and individuals. At this time, priority areas for investigation include building design, construction technology, energy conservation, site and subdivision design, site servicing technology, residential building product development or improvement and information technology.

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EXECUTIVE SUMMARY

This executive summary provides a brief abstract of each of the papers presented at the symposium, and outlines key issues covered in the introduction.

1. Introduction

The introduction reviews key areas of concern that were identified in the course of the symposium. These include the relationship between human health and comfort, the setting and interpretation of air quality standards, and the investigation and resolution of problems.

2. Toxicological Issues

Results of recent research on indoor air quality, as presented at the Third International Conference on Indoor Air Quality (Stockholm, 1985), are reviewed. The principles of toxicology are explained, including concepts of dose-response relationship, hazard, hyper- and hypo-sensitivity, and chemical synergy. Indoor air pollutants are discussed in terms of sources and symptoms induced in humans. Problems of regulation are outlined, and the use of risk assessment as a basis for setting standards is explained.

3. Issues in Air Quality Investigations and Research

The argument is advanced that energy conservation is not inimical to the provision of satisfactory air quality. The need to base discussions of air quality issues on a sound scientific basis is outlined, and some current problems in this area are discussed. The problems of identifying cause and effect in the investigation of alleged air quality problems are considered, and the issue of confounding factors is addressed.

4. An Epidemiological Investigation of an Air Quality Problem

The investigation and resolution of an air quality problem in an elementary school is discussed. The epidemiological method of investigation is explained.

5. A Residential Builder's Experience

The process of modifying a house to suit the requirements of an individual with extreme chemical sensitivities is discussed. Some views on individual experiences of health problems due to air quality are expressed.

6. Environmental Control in Large Buildings

The process of designing for satisfactory indoor air quality as practiced by mechanical engineers is explained. Problems of ventilation and air-conditioning in large buildings are reviewed.

7. Federal Government Activity

A survey of current work of departments, crown corporations and non-governmental organizations on indoor air quality is presented.

8. CMHC Activity

Research projects related to indoor air quality and being undertaken or funded by Canada Mortgage and Housing Corporation are discussed. Work reviewed includes ventilation guidelines, air flow in housing, carbon monoxide hazards and chimney backdraft studies, and moisture studies.

9. Specialized Equipment for Air Quality Investigations

Substances found in indoor air are discussed. Sampling of organic substances is reviewed. The use of the mass spectrometer is explained.

10. A Benchmark Study of "Healthy" Office Building

The intent of the investigation is outlined. The building is described and details of the scope of the investigation are provided. Information is presented on substances sampled, sampling methods used, and concentrations of contaminants. Some suggestions are made about simple diagnostic procedures for use when air-handling systems are being balanced or air quality complaints investigated.

11. Panel

A panel reponds to questions from symposium participants on the presentations and other matters related to indoor air quality.

1. INTRODUCTION

1.1 Purpose of Symposium

The purpose of the symposium was to provide for the exchange of information on the control of indoor air quality. This topic is currently hotly debated by professionals and the media alike. The symposium was intended for the people who deal with air quality problems on a day to day basis in their work environment, whether in designing or operating buildings, or in assuring public health and safety. Speakers discussed aspects of the problem including:

(i) effects on human comfort and health,

(ii) effects on the physical fabric of buildings,

(iii) regulatory issues,

(iv) practical problems of building design,

(v) investigations of building air quality and response to complaints, and

(vi) government activity.

More than 60 people attended the symposium, comprising a knowledgeable audience that included health inspectors, occupational hygienists, mechanical engineers, architects, and medical doctors. A list of those who attended may be found in Appendix A.

1.2 Discussion

It is common to deal with technical problems in housing and other construction sectors separately. Air quality is an issue where this approach is inappropriate because the population at risk is the same in both cases. For instance, workplace exposure standards based on "relaxation time" (zero exposure outside working hours) are not sound if the exposed individual spends substantial time in a home environment where the same contaminants are present. As well, the health issues are the same whether one is considering the home or the occupational environment. Further, many of the investigative techniques can be applied to both residential and non-residential sectors.

The most common reaction of the symposium participants after three days of lectures was that the problem of indoor air quality was more complex than they had thought. There was some disappointment at the lack of "black and white" answers, and at the lack of "rules of thumb" for practitioners. Scientific studies have produced differing, and sometimes conflicting, results. Scientists differ in their personal views. All of this can be distressing to professionals and laymen alike.

Education is certainly one answer. It is important that people concerned with the provision and maintenance of air quality understand the reasons underlying differences and disagreements. It is also important that a clear understanding of concepts be developed, and to ensure that terminology is used consistently and correctly. Only then will the answers provided by research

be understood and properly applied in practice.

1.3 Summary

It would take a considerable amount of space to review all that transpired. This section will cover some of the highlights.

1.3.1 Human Health and Comfort

Human health and comfort is the focus of the air quality debate. However, health and comfort are very different problems. Most complaints about air quality result from discomfort or irritations rather than experiences of serious illness. These may contribute to reduced performance of workers.

A more serious issue is the possible carcinogenicity of various substances found in indoor air. Such effects would not normally be noticed by a building occupant for a period of decades. Dr. Roger's review of toxicology made very clear the difficulties involved in establishing carcinogenicity. While comfort is easy to determine, toxicological studies that provide information on carcinogenicity are extremely complex and expensive. Current methods cannot even answer all of the questions posed regarding the effects of mixtures of chemicals.

As well, there is the matter of the minority of individuals who seem to suffer immediate and extremely adverse effects from concentrations of airborne substances that are not even noticeable to the majority of the population. Dr. Thompson's paper attacks some of the fallacies that have emerged in debates on this issue.

Some professionals are concerned about indoor air quality because of its effects on the building itself. For instance, moisture is sometimes considered to be a pollutant, or at least an air quality issue, when it results in rot in wood-frame walls.

1.3.2 Substances of Concern

Inconsistent use of terminology complicates discussion of indoor air quality issues. Definitions of pollutant include "a substance not normally found in the lower atmosphere", "a material with known toxic properties", and "a harmful material present in concentrations sufficient to render an environment unfit for its intended use". The editor feels that the last definition is the most useful, with the term "contaminant" denoting a potentially harmful substance at concentrations greater than "background" levels.

The following table prepared by Bruce Small for CMHC summarizes information on indoor pollutants. For a more detailed discussion of substances that are designated as pollutants, the reader is referred to Indoor Pollutants, available from the National Academy Press, 2101 Constitution Avenue NW, Washington, DC, 20418, USA (202-334-3313).

Table 1.1. Summary of information on indoor pollutants.

POLLUTANT	DESCRIPTIVE SUMMARY	HEALTH EFFECTS
Aerosols	Many consumer products yield high pollutant concentrations, which could present serious health hazards. Persons with cardiovascular or pulmonary impairment are at greatest risk.	Reduces tracheal mucous velocity and impairs airway defence mechanisms. No data on long-term use. Complaints of headaches, nausea, shortness of breath, eye irritation, skin rashes, lung inflammation, liver damage, and cardiac arrhythmia have been attributed to normal aerosol use.
Ammonia	Often present in indoor air in small quantities and is known to irritate those susceptible. Little data available on incidence or health effects at low levels.	Inhaled ammonia is an irritant that primarily effects the upper respiratory tract. If ammonia concentrations are high or exposure prolonged, the eyes may be seriously damaged.
Asbestos	Potential sources include many products no longer produced but still present in many homes. Fibres are carcinogenic.	Mesothelioma, a rare form of cancer, believed to result only from the inhalation of asbestos fibres. Asbestosis may precede mesothelioma. Unexplained breathlessness and productive cough, accompanied by pain and tightness in the chest may precede the disease by many years. Bronchogenic carcinomas, lung cancer, and cancer of the intestinal tract may also result from asbestos exposure.
Bacteria/Virus	Bacteria may grow in warm standing water (in humidifiers, for example). Transmission of infection by bacteria and virus increases with reduced ventilation.	Bacteria and viruses can produce infection, disease and allergic reactions. Respiratory viruses can be transmitted from person to person.
Carbon Dioxide	Indoor concentrations are often much greater than outdoor concentrations. Unvented kerosene heaters may produce concentrations well in excess of occupational standards.	Long-term exposure may cause changes in the acid balance if exposures exceed 5000 ppm. Concentrations at 50 000 ppm (5%) carbon dioxide in the air cause dizziness, headache and confusion. At 8-10% severe headaches, dim vision, tremors and even unconsciousness will occur if the level is maintained for 10 minutes. Concentrations of 25-30% have been associated with diminished respiration, hypotension, coma, loss of reflexes and sense of touch. At these concentrations, consciousness is lost almost immediately and death may ensue.

Source: Indoor Air Pollution and Housing Technology, prepared by Bruce M. Small for CMHC.

Table 1.1. Summary of information on indoor pollutants (continued).

POLLUTANT	DESCRIPTIVE SUMMARY	HEALTH EFFECTS
Carbon Monoxide	Major sources are gas stoves, fossil fuels, furnaces and heaters. Exposure is widespread and often at levels above outdoor standards. Faulty furnaces have given rise to fatal carbon monoxide concentrations.	At low concentrations, shortness of breath on moderate exertion and slight headaches are reported. At higher concentrations symptoms include severe headaches, mental confusion, dizziness, impairment of vision and hearing, collapse or fainting on exertion. At extreme concentration unconsciousness or death occurs.
Chlorine	Present in the home particularly in laundry preparations and in municipal water. Chemically susceptible people are known to be affected adversely but no data are available on indoor concentrations or long-term health effects.	Affects the mucosa of the eyes and the upper respiratory tract. Headaches, irritation of nasal sinuses, sneezing, coughing, loss of voice, dizziness, anxiety, unconsciousness, profuse tearing, and sensitivity to light have been reported.
Formaldehyde	Major sources include building materials and furnishings. Exposure can lead to generalized chemical susceptibility. Suspected to be a carcinogen.	Reported health effects include skin, eye and throat irritation, respiratory disorders and allergies, and a decreased threshold of reactivity with prolonged exposure. High exposure levels have produced nasal cancer in rats. Principal effect of the other aldehydes is irritation of the eyes and skin.
Fungi (mould)	Universally present in homes but may grow significantly if there are sources of dampness. Moulds contain potent allergenic compounds and can affect health adversely.	Produces respiratory disease by precipitating allergic reaction in the respiratory tract. More rarely produces pulmonary infections.
House Dust	Covers a wide variety of compounds and mites that can be allergenic and therefore may adversely affect the health of a significant proportion of the population. A reasonable degree of avoidance for affected persons is feasible and recommended.	Contains allergenic compounds that may initiate and provoke immunologically hypersensitive reactions. Depending on the nature of the dust, responses may be due to irritation or may be immunological.
Nitrogen Oxides	Tobacco smoking and indoor combustion are the major sources. Increased incidence of illness has been correlated with elevated NO_2, and other pollutant levels in the home.	Known to cause burning and choking sensations in the upper respiratory tract at concentrations of 25 to 75 ppm. Prolonged exposure will cause oxidization of hemoglobin and more severe symptoms such as sleepiness, feelings of intoxication and loss of consciousness. Nitrogen dioxide may cause lung damage by corroding the mucous lining of the lung.

Table 1.1. Summary of information on indoor pollutants (continued).

POLLUTANT	DESCRIPTIVE SUMMARY	HEALTH EFFECTS
Organic Vapours	Indoor air often contains low levels of complex mixes of organic vapours which, in combination, exceed outdoor and other standards. Many compounds present have detrimental effects at high concentrations and are known to affect hypersusceptible persons at levels commonly found in homes.	Little is known about the short- and long-term effect of many of the organic compounds found at low levels in residential environments. The health effects differ with each organic compound and range from respiratory irritation to being suspected carcinogens.
Ozone	Improperly maintained electrostatic air filters can produce ozone at levels above outdoor ambient standards. Persons already hyper-reactive are at greatest risk.	Irritation of the mucous membranes of the upper respiratory tract. Decrease in visual acuity and other changes in ocular parameters. Laboratory animals experience increased death rates, sphering of red blood cells, structural changes in the nuclei of myocardial tissue, increased neo-natal death rate.
Pesticides	Widely used outdoors. Measurable concentrations found in human blood and tissue. Numerous incidents of illness have been reported and pesticides are suspected to be potent sensitizers that can lead to a more widespread chemical susceptibility.	Mild toxicity characterized by headache, dizziness, numbness and weakness of the extremities, apprehension and irritability. When large amounts are absorbed, symptoms may include muscular tremors, loss of balance, and convulsions. Death is usually due to cardiac failure or respiratory collapse.
Radon/Radon Decay Products	Present in most homes and may present a measurable cancer risk. Concentrations are greatest in energy-efficient homes with reduced ventilation.	Exposure to radon and its progeny at high concentrations causes lung cancer. Risk is directly proportional to dose.
Sulphur Dioxide	Indoor concentrations often lower than those outside due to absorption on building surfaces. Fossil fuel combustion is the primary indoor source.	Irritation of the upper respiratory tract. Acute exposure above 20 ppm produces choking and sneezing. Direct effect of the epithelial tissue of the lung is presumed to be the predominant hazard.
Suspended Particulates	Various household materials and activities in addition to smoking produce suspended particulates. Some particulates can cause irritation and lung disease. More research is needed, particularly concerning possible carcinogens.	Mineral, wool, and glass fibres, silica dust, organic dust, and chemicals absorbed in them can irritate the mucous membranes of the digestive and upper respiratory tract as well as the skin and eyes.
Tobacco Smoke	Tobacco smoke is the major source of inhaled suspended indoor particulates, producing concentrations well in excess of outdoor air standards. Contains known and potent carcinogens.	Primary effects at low concentrations are coughing, headache, nausea, and irritation of the eyes, nose, and throat. A number of polynuclear aromatic hydrocarbons in tobacco have been identified as active tumorigenic agents. Tobacco smoke also interacts with asbestos exposure, increasing the cancer risk.

1.3.3 Standards

While toxicological research continues, members of other professions must set and interpret standards now. This means that most, if not all, standards are somewhat arbitrary. Standards for maximum concentrations of various substances must be translated into criteria which can be applied by the professions and trades involved in building design and maintenance. This is not close to being a fully resolved problem.

1.3.4 Investigation and Remediation of Problems

Building operators and health inspectors in particular must evaluate environments to determine whether they meet the relevant standards. They must deal with individuals who complain of problems yet who are exposed to environments that apparently meet standards. Dr. Kayser's presentation delves into this issue, and leaves the reader with some practical suggestions for action. As Dr. Thompson notes, abandoning energy conservation is not a rational response to air quality problems. Improved air handling system management can result in both improved air quality and energy savings. As well, other measures should be considered, such as elimination and control of contaminant sources.

1.3.5 Conclusion

A program of continuing education that keeps those in practice aware of research and communicating with each other will be essential to continued progress in assuring adequate indoor air quality.

1.4 Organization of the Document

The various sections each represent a particular paper, and occur in the same order in which they were presented at the symposium.

2. TOXICOLOGICAL ISSUES

Dr. R. Rogers, Concordia College, Edmonton
(formerly toxicologist, Alberta Occupational Health & Safety)

In an article published in Science in 1984, John Spengler, from Harvard, and Ken Saxton, from the Department of Health in California, stated that they believed the indoor air pollution would have more significant adverse health effects than pollution of outdoor air.

We are now seeing buildings that are entirely reliant on their ventilation systems to provide clean air. The common practice of recirculation of indoor air and a lack of adequate maintenance in some systems will, I expect, lead to a substantial upswing in health problems related to indoor air quality. Another contributing factor is the large amount of time people currently spend indoors.

2.1 Third International Conference on Indoor Air Quality, Stockholm

2.1.1 Positions of Attending Countries

Last summer, I attended the Third International Conference on Indoor Air Quality in Sweden. Attendees came from 31 countries, mostly from cold climate regions. The large majority were from the United States and Sweden. Only 4 percent of the registrants were from Canada. I was the only representative of a Canadian provincial government at the conference. Canadian politicians are not convinced that indoor air quality is a problem. Convinc-

ing them that a problem exists is one hurdle in making progress on this issue.

Gertrude Sigurtsen, the Swedish Minister of Health and Social Affairs, said in the opening address that future Swedish health policies would be increasingly directed toward the environment. Between 1990 and 2000, health policy would reflect this concern with emphasis being placed on preventative measures.

In 1982, the United States government launched its first program in indoor air quality research through the Environment Protection Agency. California was the first state to establish a research program in this area.

2.1.2 Topics and Conclusions

The following areas of study could be identified among the papers presented at this conference:

(i) sensory and hyper-reactivity reactions,

(ii) chemical characterization of personal exposure, and

(iii) building ventilation and thermal climate.

Most of the activity was in sensory and hyper-reactivity reactions. The proceedings of the conference were compiled in a proceedings titled "Indoor Air".

As a general observation, it would appear that potential problems associated with indoor air quality can be divided into two broad areas:

(i) In the case of large buildings (the non-industrial occupational environment), there have been numerous reports of "sickness". The precise causes of worker complaints remain unclear and linkage with the presence of specific chemicals has not been made (except where micro-organisms such as Legionella have been present).

(ii) In the case of the residential environment, much of the work conducted so far has centered on potential health problems arising from the presence of numerous chemicals, micro-organisms or radioactivity, generally at very low concentrations. An exception is formaldehyde in which case actual health problems have been reported.

With the possible exception of formaldehyde, indoor air quality problems have not been adequately investigated. Further developments are required in terms of identifying and quantifying exposures to indoor air pollutants, improving personal monitoring devices, designing systematic epidemiological studies of indoor environments, and identifying persons who are hypersensitive to airborne contaminants.

Some specific recommendations or conclusions arising from the symposia attended include:

- sources and problems associated with formaldehyde are comparatively well understood and the need for research is not as urgent as it was 3 years ago,
- formaldehyde appears not to be a potent human carcinogen,
- relationships between particle levels indoors and outdoors do not appear to exist; indoor levels are often higher than those outdoors,
- mutagenic activity of particulates is more pronounced in smokers' homes,
- symptoms of "sick building syndrome" (SBS) have been

shown to have differences from mass psychogenic illness; mucous membrane problems are dominant in SBS,

- there is a need to develop standardized questionnaires for investigating sick buildings; objective measurements of health effects should accompany administration of these questionnaires,

- future research should emphasize identification of sources and levels of volatile organics and particulate organic matter, and

- the two fundamental approaches to setting standards for indoor air are specification (sometimes known as the prescriptive approach) and performance-based regulation need to be rationalized (an example of the former is regulation of air supply requirements, an example of the latter is limitation of concentrations of a substance).

2.2 Indoor Air Quality as a Health Problem

I will discuss chemical contaminants and chemical contamination problems as opposed to micro-organisms and allergies. The former are handled differently from microbiological problems involving a sensitization reaction.

The World Health Organization defines health in the following way: health is a state of complete physical, mental and social well-being, not merely the absence of disease or infirmity. Although this definition seems innocuous, note the reference to mental and social well-being. The psychological aspects of health are very important in indoor air quality work. For instance, if one examines the prevalence of symptoms in subjects exposed to urea formaldehyde foam insulation (UFFI), there is a very high occurrence of neuropsychiatric symptoms. I do not believe that it is possible to eliminate the psychological component in considering the health consequences of contaminated

indoor air. However, this complicates the investigation of physiological reactions.

Frequently, complaints involve very nondescript and clinically evasive symptoms. For instance, if a person complains to a doctor about headaches, the doctor is not likely to associate such complaints with the quality of air in the residence or place of work because it is such a non-specific complaint (see Table 2.1, below). However, headaches are a very common symptom of air quality problems.

Table 2.1. Types and frequency of symptoms associated with indoor air quality problems.

Complaint	% of Buildings
Eye Irritation	81
Dry Throat	71
Headache	67
Fatigue	53
Sinus Congestion	51
Skin Irritation	38
Shortness of Breath	33
Cough	24
Dizziness	22
Nausea	15

2.3 Basic Principles of Toxicology

I believe that basic toxicological principles are essential in understanding problems of indoor air quality, particularly in the case of chemical contaminants. I find a lot of articles in the media that show a complete lack of understanding of these concepts, and lead people to believe that almost everything will cause cancer. The point has been reached where the public feel that everything is harmful, and that there is no point in taking action. Scientists have been inept at communicating with the public via the press.

Paracelsus (1493) noted that all substances are poisons. The only difference between a poison and a remedy is the dose. Water, oxygen, and salt can be fatal if taken in sufficient quantities. Pure oxygen can cause lung damage.

Toxicology is the study of the harmful effects of chemicals or physical agents on biological systems. Note that the mechanisms of harmful effects are emphasized, as well as the conditions under which these effects occur. Toxicology is not a basic science, it is an interdisciplinary study. It draws extensively on pharmacology, physiology, public health, immunology, and other medical disciplines.

Relatively limited resources have been made available for laboratory work on human reactions to contamination or pollution of indoor air. Hence, toxicologists are forced to rely heavily on information generated by existing procedures set up to assess

chemicals such as pesticides and new pharmacological products.

2.3.1 Absorption of Chemicals

To have an effect, a chemical must first be absorbed. If exposure occurs, but there is no absorption, then there will not be any problem. In dealing with the occupational work force, one of the most economical measures to prevent exposure to carcinogens is to clothe workers in environmental suits with uncontaminated air supplies.

In the case of airborne elements entering the body through the lungs, one will be concerned with characteristics such as lipid solubility and water solubility which affect how much of that chemical will move into the body and in what form. From the lungs, a chemical would generally enter the body through the blood stream. It will be present in free form, in equilibrium in terms of binding specifically or nonspecifically to proteins that are in the blood stream. The blood will relocate the material through the body. Fat in the body may act as a storage deposit; for instance, DDT will accumulate in body fat. The liver may cause biotransformation of compounds to occur. Other organs may also do this. The chemical will ultimately be excreted in its parent form, or as one or more metabolites. The question then is: Which is most toxic, the parent form or the metabolites?

Material may be ingested with food or water, inhaled, or taken intravenously. Only inhalation is of interest in most air quality problems. Once in the blood stream, a chemical may be depo-

sited anywhere in the body. The ultimate destination is a function of the chemical characteristics of the substance. In toxicological work, it is necessary to know not only where a substance initially enters the organism, but also where it is ultimately deposited.

If a substance is absorbed, effects may be either

(i) immediate or delayed,

(ii) acute (short-term) or chronic (long-term), or

(iii) local or systemic.

Immediate effects show up almost directly after absorption. This sort of effect may be observed when barbiturates are ingested. Delayed effects require a period of time between the initial exposure and the appearance of symptoms. Some cancers have a long latent period.

People most often express concerns about effects of long-term low level exposure to substances. These are very difficult to assess, as I will explain below.

Local effects occur at the site of first contact. With an airborne substance, this would be at the respiratory mucosa. Systemic effects occur after absorption and distant from the point of entry. Most chemicals fall into the systemic category. This brings us to the concept of the critical organ - the point where a toxicant concentrates. For instance, it is possible to inhale lead. Lead accumulates in the bone and then moves to soft tissue such as the central nervous system. The latter is the sensitive

tissue. One important task in toxicology is determination of what the target organs will be for a particular chemical. Fortunately, animal test systems allow us to do this.

2.3.2 Dose-response Relationships

The most fundamental and pervasive concept in toxicology is the dose-response relationship (see Figure 2.1, page 19). That is, when there is an exposure to a substance, there will be a response. This response may range from a very simple physiological change to death. Within species there is not a great variation in dose-response curves. However, between species there can be a considerable variation. This causes complications in using results from laboratory studies of animals to draw inferences about human responses. The dose-response relationship is based on three assumptions. The first is that the response is a function of the concentration of the toxicant at a receptor site. The second is that the concentration is a function of the dose that is received - the more that is received, the more of the toxicant reaches the target tissue. The third assumption is that the response and the dose are causally related. Demonstrating the latter can be difficult.

Dose refers to the concentration of the substance to which a person is exposed. In the case of a substance mixed with air, this may be expressed in ppm (parts per million), ppb (parts per billion), or ppt (parts per trillion). This is equivalent to milligrams per litre when dealing with ingestion of a fluid. In the case of gasses, milligrams per cubic metre are used to indicate

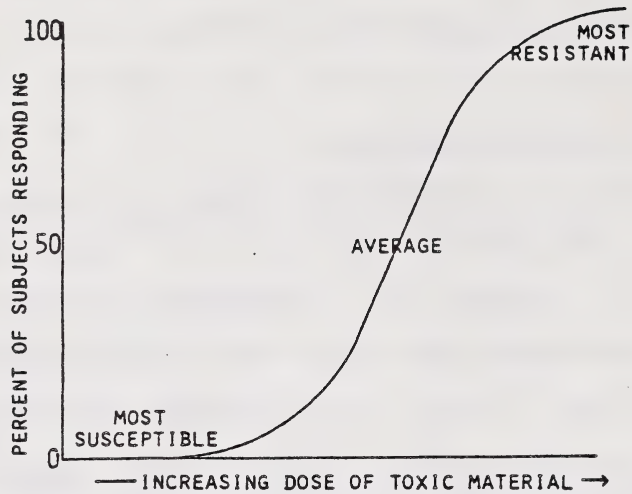

Figure 2.1. Example of dose-response curve

concentration. This is the ppm multiplied by the molecular weight.

Three possibilities exist when there is not an immediate reaction (see Figure 2.2, page 20):

(i) Gradual build-up (no excretion) eventually leads to the same result as an acute dose; there are not many chemicals that do this.

(ii) Most chemicals are excreted to some extent between doses; however, there is a gradual build-up due to metabolism. Lead exposure is a good example of this. Lead is a bone-seeker. Gradually there will be a build-up in the bones. Toxicity will occur if there is a release of lead from the bone into the system.

(iii) The third possibility is a chemical that is largely eliminated between doses.

Many organisms follow Gaussian or normal distributions in their

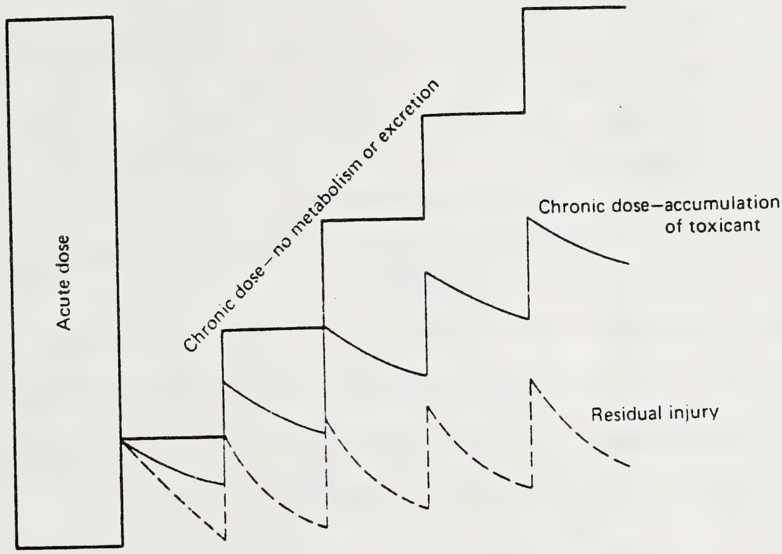

Figure 2.2. Example of dose-response curve: repeated regular doses.

response to chemicals (see Figure 2.3, page 24). This means that some people will be much more resistant than the normal population and some much more sensitive. Of course, the "sensitives" are of greatest concern. A quantal response curve is shown in Figure 2.4 on page 22. It indicates the range of doses required to produce a quantitatively identical response in a large population. The vertical axis shows the response, and the horizontal shows the dose. Populations tend to respond in a sigmoid fashion.

The quantal response curve can be translated into a cumulative response curve (see Figure 2.4 on page 21). This quantal curve

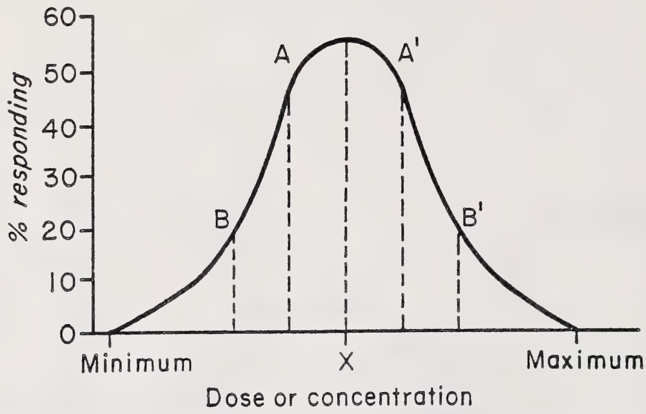

Figure 2.3. Example of normal frequency distribution.

is linear between 16 and 84%. The 5Ø% population mortality response in whatever population is being considered is called LD5Ø or lethal dose 5Ø. This is standard criteria used to compare the toxicity of different chemicals.

In the case of indoor air quality, there is variety of things that can lead to a response. Ultimately, we are interested in how the critical tissue will respond to a given concentration of that material. We would therefore start with the concentration of the substance in the environment (eg. using metal in soil or plants as indicators). We would then look at concentration in ambient air or food, and the population of people exposed. It would be desirable to measure parameters such as metal concentration in critical cells. Unfortunately, this involves internal organs, and large scale sampling is not possible. Therefore, attempts are made to estimate concentrations in the body through the use of biological monitors - such as hair, blood, and urine.

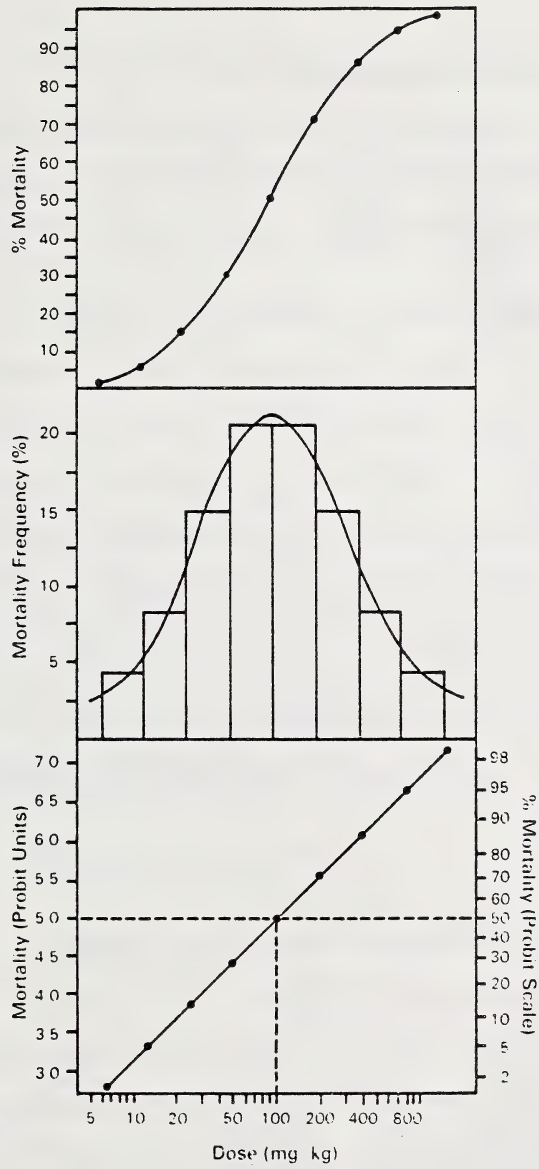

Diagram of quantal dose-response relationship. The abscissa is a log dose of the chemical. In the top panel the ordinate is percent mortality; in the middle panel the ordinate is mortality frequency; and in the bottom panel the mortality is in probit units.

Figure 2.4. Example of quantal and cumulative response curves.

2.3.3 The Concept of Hazard

Hazard is the potential of a substance to cause damage to people. Hazard identification involves determining what the hazard is to people under a certain set of conditions.

Toxicity is the inherent capacity of a material to produce an injury in a living organism. Every material is potentially toxic; all that is required is a large enough dose. Toxicity rating charts are based on the assumption that anything for which LD5Ø is less than 5 mg/kg is supertoxic, and above 15g/kg is non-toxic (see Tables 2.2 and 2.3 on page 24). The middle range is simply labelled toxic.

It is not easy to produce such a chart for the indoor environment. There are a lot of chemicals for which LD5Ø has not been determined.

2.3.4 Reserve Functional Capacity in Humans

Mammals, including human beings, have reserve functional capacity. Our organs are endowed with a capacity to continue functioning and meet the minimal requirements of the organism even if they are partially dysfunctional. For example, if 5Ø percent of the liver of a dog is surgically removed, the dog will still respond normally. People are therefore able to recover, or to adjust to environmental insults such as toxic elements in the environment.

For instance, people recover from sunburns. The body is pushed

Table 2.2. Toxicity of selected chemicals.

AGENT	ANIMAL	ROUTE	LD_{50} IN MG/KG
Ethyl alcohol	mouse	oral	10,000
Sodium chloride	"	IP	4,000
Ferrous sulfate	rat	oral	1,500
Morphine sulfate	"	"	900
Phenobarbital, sodium	"	"	150
DDT*	"	"	100
Picrotoxin	"	SC	5
Strychnine sulfate	"	IP	2
Nicotine	"	IV	1
d-Tubocurarine	"	"	0.5
Hemicholinium-3	"	"	0.2
Tetrodotoxin	"	"	0.10
Dioxin (TCDBD)†	guinea pig	"	0.001
Botulinus toxin	rat	"	0.00001

IP = Intraperitoneal, IV = Intravenous, SC = Subcutaneous
LD_{50}'s are listed according to averages of nearest round figures from many sources. The principal sources are: Barnes, C. D. and Eltherington, L. G., *Drug Dosage in Laboratory Animals—a Handbook*, University of Calif. Press, Berkeley, 1964; *Handbook of Toxicology*, Vol. 1, Spector, W. S., ed., W. B. Saunders Co., Philadelphia, 1956; Goldenthal, E. I. Compilation of LD_{50} values in newborn and adult animals, *Tox. and Appl. Pharmacology 18*: 185–207, 1971.

* DDT = P,P^{1} dichlorodiphenyl trichloroethane
† TCDBD = 2,3,6,7 tetrachlorodibenzodioxin

Table 2.3. Toxicity rating chart.

TOXICITY RATING OR CLASS	PROBABLE ORAL LETHAL DOSE DOSE	FOR AVERAGE ADULT
1. Practically nontoxic	> 15 g/kg	More than 1 quart
2. Slightly toxic	5-15 g/kg	Between pint and quart
3. Moderately toxic	0.5-5 g/kg	Between ounce and pint
4. Very toxic	50-500 mg/kg	Between teaspoonful and ounce
5. Extremely toxic	5-50 mg/kg	Between 7 drops and teaspoonful
6. Supertoxic	<5mg/kg	A taste (less than 7 drops)

past the point of compensation (see Figure 2.5 on page 25). Repair is required. Normally the repair mechanism is very effec-

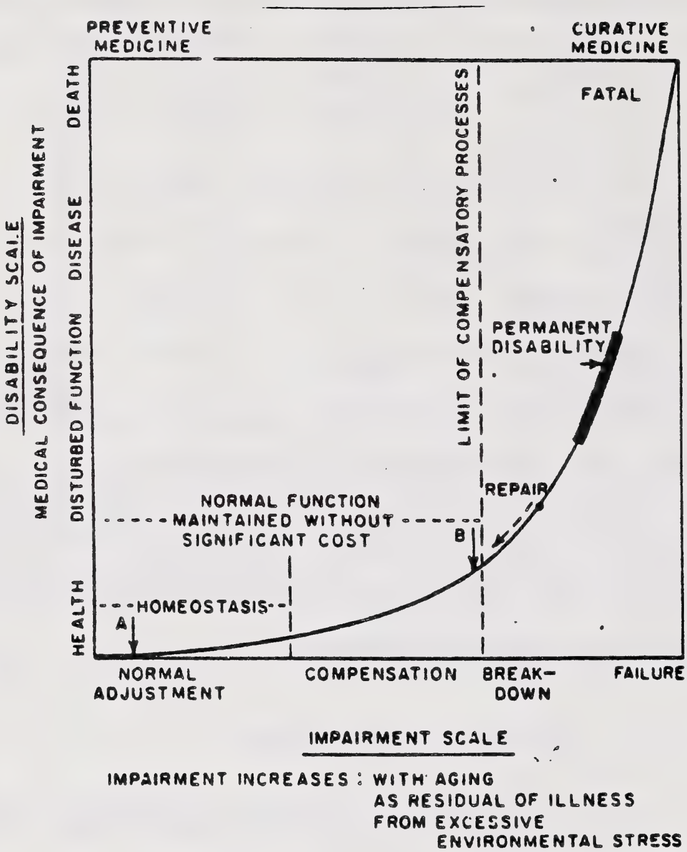

Figure 2.5. Physiological responses to environmental insults.

tive, but, with age, its performance deteriorates. In the case of skin cancer, the capacity of our bodies to repair an ultraviolet radiation insult diminishes. We see that most skin cancer occurs in the older part of the population.

Tolerance is the ability of an organism to show less response to a specific dose of a chemical than it showed on prior occasions. A reduced response occurs when the body adapts. For instance, in

the case of respiratory epithelial damage by ozone, a second exposure produces a lesser response. The same thing is true of cigarette smoking in young adults. Initially there is nausea, but with repeated exposure the body becomes more tolerant.

This phenomenon is not well understood. Some causes may be impaired absorption or translocation of substances. Enhanced excretion and biotransformation are other possible explanations.

2.3.5 Hyper and Hypo-sensitivity

Hypersensitivity and hyposensitivity are used in a different way in the field of toxicology than they are in an immune sense. So-called "hypersensitive reactions" are misnomers from a toxicological viewpoint. By hypersensitives, toxicologists are referring to people who respond more to a subsequent dose than to any previous dose. Immunologists use the term to refer to people who are much more sensitive to a substance than the rest of the population.

2.3.6 Interaction of Chemicals

Usually toxicological research involves the development of dose response curves for single chemicals. Some work has been done on pairs of chemicals. However, in the indoor environment we are breathing mixtures of large numbers of chemicals. The crux of the indoor air quality problem is determining the toxicity of the mixtures of chemicals involved. Let us consider the possible combined effects of mixtures of toxic chemicals.

The additive effect occurs when the combined effect is exactly equal to the sum of the toxicities. An example would be two organo-phosphate insecticides. Together they will produce additive cholinesterase inhibition because they are both acting on the same substrate.

The synergistic effect occurs when the combined effect is much greater than the sum of the individual effects. Carbon tetrachloride and ethanol are both hepatotoxic (cause liver problems). The injury caused by a mixture of the two is much greater than the same doses received independently.

Potentiation occurs when a chemical is not toxic, but becomes toxic when combined with another. An example is the combination of isopropanol and carbon tetrachloride. The former is not hepatotoxic; however, carbon tetrachloride (CCl_4) is. If isopropanol is added to CCl_4, then the hepatotoxic carbon tetrachloride effect is much increased.

Antagonism occurs when chemicals interact in such a way that the toxic effect is reduced. This occurs when a substance interferes with another's actions. Antagonism may be physiological - for instance, convulsion can be treated with barbiturates. Chemical antagonism occurs when there is a reaction between chemicals which results in a less toxic product. Metals such as lead or mercury can be made less toxic by using a chelator such as BAL. This can be hazardous because BAL has its own toxicities. Antagonisms which alter the absorption, metabolism or distribution of a chemical are called dispositional. For instance, the

absorption of some poisons can be reduced by administering ipecac. Substances may be used to increase the biotransformation of pesticides, or to use a chemical to block the receptor. As an example, it is possible to halt the effects of an organophosphate poison by giving atropine, which will block the receptor site on the post-synaptic neuron.

2.3.7 Chemical Allergies versus Toxic Responses

Some substances cause chemical allergy and can induce an immune response. Toluene di-isocyanate (TDI) causes the formation of IgE antibodies which are released from mast cells on subsequent exposures. TDI is found in many paints. After the initial exposure to the compound or its metabolic product (called the haptene), the chemical will enter the body and conjugate with one of the endogenous proteins to form the so-called antigen. That antigen, on first exposure, will then elicit the formation of antibodies. On subsequent exposure to the same chemical, an antigen-antibody reaction will occur immediately. This leads ultimately to cellular damage.

It is therefore important, when dealing with indoor air quality, to distinguish between those individuals with chemical allergies and those with a simple toxic response to a chemical. They have different problems - the dose-response relationship does not apply to immune responses.

2.4 Indoor Air Pollutants

Typically one finds different pollution problems indoors from outdoors. One cause of such problems is the switching off of ventilation systems at night to reduce energy expenditures. Chemical emissions can lead to increased concentrations overnight.

2.4.1 Sources

It is important, in examining indoor air quality problems, to determine the sources of pollutants (see Table 2.4 on page 30). For example, at the Mackenzie Health Sciences Centre in Edmonton, the exhaust for a truck loading zone was located next to an air intake. This caused a number of health problems in the occupants of the building. It was resolved by extending a stack up the side of the building for the air intake. In this case the indoor pollution was due to an outdoor source. The problem of adjacent exhausts and intakes is a common one.

A problem in measuring some substances is their transience. For instance, chemical cleaners applied in the evening may lead to complaints the following morning. By the time Occupational Health and Safety investigators arrive, 2 days or a week later, to make measurements the pollutants have largely been dispersed.

The inhalation of cigarette smoke by nonsmokers is currently a very controversial issue. At the Stockholm conference, it was generally maintained that there is no definitive proof to show that "passive" smoking increases the risk of adverse health

Table 2.4. Sources of indoor pollutants.

SOURCES	POLLUTANT TYPES
OUTDOOR	
Stationary Sources	SO_2, CO, NO, NO_2, O_3, Hydrocarbons, Particulates
Motor Vehicles	CO, NO, NO_2, Lead, Particulates
Soil	Radon
INDOOR	
Building Construction Materials	
Concrete, Stone	Radon and other radioactive elements
Particleboard	Formaldehyde
Insulation	Formaldehyde, Fiberglass
Fire Retardant	Asbestos
Adhesives	Organics
Paint	Organics, Lead, Mercury
Building Contents	
Heating and Cooking Combustion Appliances	CO, NO, NO_2, Formaldehyde, Particulates
Copy Machines	Organics
Water Service; Natural Gas	Radon
Human Occupants	
Metabolic Activity	H_2O, CO_2, NH_3, Organics, Odors
Biological Activity	Microorganisms
Human Activities	
Tobacco Smoke	CO, NO_2, HCN, Organics, Odors Particulates
Aerosol Spray Devices	Flurocarbons, Vinyl Chloride, CO_2, Odors
Cleaning and Cooking Products	Organics, Odors
Hobbies and Crafts	Organics, Odors

effects in non-smokers. There were studies claiming both that there are and are not effects.

This is a good example of a situation where the contentious subject can be measured and chemicals can be identified that are carcinogenic or mutagenic (see Table 2.5 on page 32). Yet there is still disagreement about the hazard. While this upsets a lot of people, I would think that at the levels typically found, unless there was an extremely long exposure time, there would be few effects.

People themselves give off chemicals such as acetone (50 mg/day), phenols, and toluene. This, in itself, is another source of indoor air contamination.

More serious problems may result when equipment such as humidifiers are not cleaned enough to prevent the development of various biological agents.

2.4.2 Symptoms

Symptoms most commonly reported in association with air quality problems include eye irritation, dry throat, headache and fatigue. It is very difficult for the medical profession to pin down the causes of the symptoms because they are very non-specific, and it is difficult to establish a cause-effect relationship.

Table 2.5. Composition of mainstream and sidestream cigarette smoke.

Characteristic or Compound	Concentration, mg/cigarette[a] Mainstream Smoke (1)	Sidestream Smoke (2)	Ratio, 2:1	Reference
General characteristics:				
Duration of smoke production, s	20	550	27.5	19
Tobacco burned	347	411	1.2	15
Particles, no. per cigarette	1.05×10^{12}	3.5×10^{12}	3.3	24
Particles:				
Tar (chloroform extract)	20.8	44.1	2.1	16
	10.2[b]	34.5[b]	3.4	16
Nicotine	0.92	1.69	1.8	16
	0.46[b]	1.27[b]	2.8	16
Benzo[a]pyrene	3.5×10^{-5}	1.35×10^{-4}	3.9	10
	4.4×10^{-5}	1.99×10^{-4}	4.5	18
Pyrene	1.3×10^{-4}	3.9×10^{-4}	3.0	10
	2.70×10^{-4}	1.011×10^{-3}	3.7	18
Fluoranthene	2.72×10^{-4}	1.255×10^{-3}	4.6	18
Benzo[a]fluorene	1.84×10^{-4}	7.51×10^{-4}	4.1	18
Benzo[b/c]fluorene	6.9×10^{-5}	2.51×10^{-4}	3.6	18
Chrysene, benz[a]anthracene	1.91×10^{-4}	1.224×10^{-3}	6.4	18
Benzo[b/k/j]fluoranthrene	4.9×10^{-5}	2.60×10^{-4}	5.3	18
Benzo[e]pyrene	2.5×10^{-5}	1.35×10^{-4}	5.4	18
Perylene	9.0×10^{-6}	3.9×10^{-5}	4.3	18
Dibenz[a,j]anthracene	1.1×10^{-5}	4.1×10^{-5}	3.7	18
Dibenz[a,h]anthracene, ideno-[2,3-ed]pyrene	3.1×10^{-5}	1.04×10^{-4}	3.4	18
Benzo[ghi]perylene	3.9×10^{-5}	9.8×10^{-5}	2.5	18
Anthanthrene	2.2×10^{-5}	3.9×10^{-5}	1.8	18
Phenols (total)	0.228	0.603	2.6	13
Cadmium	1.25×10^{-4}	4.5×10^{-4}	3.6	27
Gases and vapors:				
Water	7.5[c]	298[d]	39.7	13
Carbon monoxide	18.3	86.3	4.7	32
	—	72.6	—	26
Ammonia	0.16	7.4	46.3	20
Carbon dioxide	63.5	79.5	1.3	20
NO_x	0.014	0.051	3.6	20
Hydrogen cyanide	0.24	0.16	0.67	31
Acrolein	0.084	--	—	31
	--	0.825	—	26
Formaldehyde	—	1.44	—	26
Toluene	0.108	0.60	5.6	32
Acetone	0.578	1.45	2.5	32
Polonium-210, pCi	0.04-0.10	0.10-0.16	1-4	7

[a]Unless otherwise noted. [b]Filtered cigarettes.
[c]3.5 mg in particulate phase; rest in vapor phase.
[d]5.5 mg in particulate phase; rest in vapor phase.

From Indoor Pollutants, National Academy Press, Washington, D.C. P. 157

2.5 Regulatory Issues and Risk Assessment

The question arises as to how society can go about regulating the environmental concentrations of toxic substances. The UFFI fiasco has revealed some of the problems involved in regulating chemicals. One of the most significant factors preventing the provision of research funds for indoor air quality work, is the fact the politicians are not convinced there is a problem. The reason is that there is not a great public outcry. The Lodgepole incident was an example of what can happen. Indoor air pollution began to bother people. This did contribute to the establishment of a major research program.

2.5.1 Government Intervention

One form of government intervention is regulation, although there are other approaches. These include incentives and information. The rationale for government intervention is reduction of the incidence of preventable illnesses. Regulations are created to redress imbalances of power between two parties. For instance, industry is usually more powerful than the individual worker. Government may intervene of its own accord or due to the influence of an interest group, some of which I have labelled "high stakes" due to their power as lobbies in particular areas. These include trade associations, organized labour, and farm groups (see Figure 2.6, on page 34).

The following steps are involved in developing a regulation:

(i) establish a need,

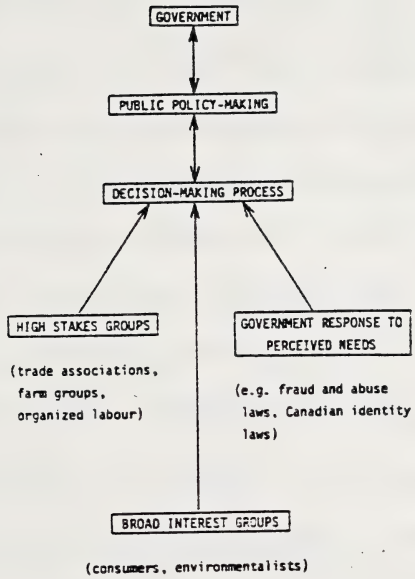

Figure 2.6. Interest groups affecting the decision-making process.

(ii) establish a desired outcome,

(iii) perform a risk assessment,

(iv) assess non-health issues such as economic and political consequences, and

(v) review the appropriateness of the regulation once it is in place.

In order to make a regulation, information is required from a number of sources. This is where problems often arise. It is commonly perceived that formulating regulations is a strictly technical process that can be left to scientists. However,

scientific considerations are only one aspect of the basis for a regulation. Other elements that enter the process are social, political, legal, and economic. This perhaps explains why many government regulations are nebulous.

A standard is part of a regulation. It is an enforceable number. A specification standard tells exactly how a satisfactory situation is to be achieved. An example is the use of air flow rates in ventilation. Performance standards simply require a result (e.g. concentration not to exceed 50 ppm). A health based standard is generated from toxicological and epidemiological data.

In occupational settings, exposures are generally greater, so it is easier to set standards than in a community setting where exposures are lower.

For example, vinyl chloride is known to be a carcinogen. Labour would typically call for zero exposure of workers. However, the only way to achieve this would be to close the factory. The government tries to find a compromise that will be acceptable in terms of both economic consequence for the industry and health consequences for the worker.

2.5.2 Risk

Risk is a probability that a loss or injury will be brought about by a particular activity. As Lawrence has put it, risk is "a compound measure of probability and seriousness of an adverse effect". As was noted above, hazard denotes the seriousness of adverse consequences. In the case of toxic chemicals, hazard depends on the susceptibility of the individual and the exposure.

People make assessments of risk continuously in their daily lives: the risk of driving without a seat belt, the risk of driving while impaired, the risk of crossing a street, and so on. Risk is relative (see Table 2.6 below).

Table 2.6. Selected risk information.

Risk Producing Activity	Risk (deaths/population/year)
Smoking (20 cigarettes/day)	5.0×10^{-3}
Motor vehicle	2.5×10^{-4}
Industrial	1.7×10^{-4}
Falls	7.7×10^{-5}
Airplane crashes	7.7×10^{-6}
Lightning	5.0×10^{-7}
Tornadoes	4.4×10^{-7}
Living in an urban area within 0.5 km of a large sour gas pipeline	2.4 x 10-7
Gasoline Truck Accidents	1.4 x 10-7

One might ask why people object to the construction of a sour gas pipeline near their homes when there are so many other hazards

involving greater risk. The answer is that people object to the added risk that they perceive.

Quantitative risk estimates are determined from information such as epidemiological and animal studies. Qualitative risk is the subjectively perceived risk. We therefore see that the psychological element once more becomes a consideration. Another important concept is population at risk. For instance, in an epidemiological study, it is possible to incorrectly conclude that there is no risk if the wrong population is studied.

A number of factors influence the acceptability of risk (see Table 2.7, below).

Table 2.7. Factors affecting the acceptability of risk.

1. VOLUNTARILY VS INVOLUNTARILY ASSUMED
2. IMMEDIATE VS DELAYED EFFECT
3. AVAILABILITY OF ALTERNATIVES
4. PROBABILITY OF EVENT OCCURRING
5. RELIABILITY OF PROBABILITY ESTIMATE
6. COMMON VS "DREAD" HAZARD
7. SIZE OF POPULATION AT RISK
8. SENSITIVITY OF POPULATION AFFECTED
9. WHO BEARS RESPONSIBILITY
10. PREVIOUS EXPERIENCE (PERSONAL BIAS)
11. SOCIOPOLITICAL CLIMATE
12. COST/BENEFIT RATIO

One is whether risk is voluntarily or involuntarily assumed. Another factor is whether the effect is immediate or delayed. People are less concerned about future events. A third is the number of options; if no alternative is available, a higher risk may be more acceptable than would otherwise be the case. Previous experience and personal bias also affect attitudes. The government is employing quantitative risk assessment in order to make decision-making more rational.

2.5.3 Steps in Risk Assessment

The following are the steps in risk assessment:

(i) identification of the hazard,

(ii) determining the risk,

(iii) evaluating the risk in terms of its potential effect on the population, and

(iv) managing the risk so as to maximize benefits to the population at large.

Hazards are identified through human experience, toxicology, or population studies (epidemiology). Risk assessment involves determining the probability of an adverse health effect as a result of exposure to a particular substance, for chemicals of different potency, other challenges and susceptibility of the individual.

2.5.4 Safety Factors

An alternative approach to risk assessment is the use of safety factors. A safe level of exposure is defined as an arbitrary fraction of that dose at which no effects are observed in a group of test animals. This is called the no observable effect level or NOEL.

Safety factors have many limitations. Firstly, they may not reflect the chemical and kinetic properties of the chemical in the body, the effects induced, and other toxicological considerations. Secondly, a safety factor is assumed not to exist for a carcinogen. Thirdly, safety factors do not take into account differences between test animals and people.

Safety factors also depend on sample sizes used in animal studies. For example, while no effect of administering a dose of a substance to a group of 10 animals might be observed, an effect might be observed if the sample size were increased to 1000 animals. Experimental design could therefore lead to erroneous conclusions.

2.5.5 The Concept of Threshold Dose

Threshold dose is defined as the dose below which no adverse effect will occur (see Figure 2.7). However, the absence of such a threshold means that there is a degree of danger at very low levels of exposure. There are biological arguments for and against the concept of threshold dose. For example, in the case of cancer, there exists a so-called "one hit" hypothesis; it

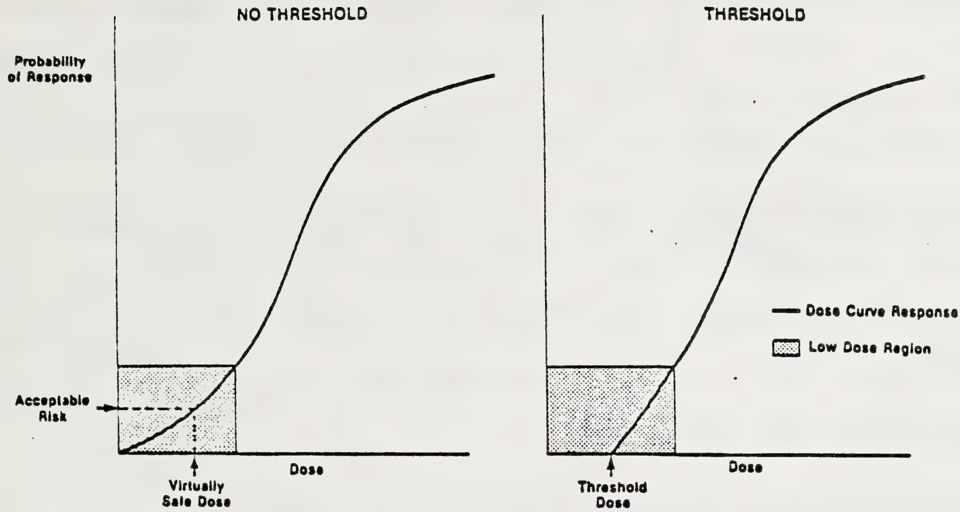

Figure 2.7. Dose-response curves exhibiting non-threshold and threshold behaviour.

holds that one biological effective dose unit causes cancer. On the other hand, concepts of bodily repair mechanisms would suggest that the body can cope with a certain level of exposure.

2.5.6 <u>Merits of Quantitative Risk Assessment</u>

Quantitative risk assessment is a more rigourous method than the safety factor method. It has the following features:

(i) based on mathematical models,

(ii) employs statistical procedures for estimating the probability of induced response versus dose rate,

(iii) does not use the threshold concept,

(iv) assumes that absolute safety is possible only if there is no exposure, and

(v) uses the concept of virtual safety which assumes

there is some risk even at very low exposures.

In the case of risk assessment, medium to high dose levels are used to develop dose-response curves for laboratory animals. Dose-response curves developed in the laboratory must be extrapolated downward into the low dose region (see Figure 2.7). At the lower portion of the curve, since no response is detected, it is almost impossible to know what shape the curve would take. There are about six models used. The model usually used in regulatory circles is the "one hit" model which involves a linear extrapolation in the low dose region.

In quantitative risk assessment, the concept of threshold dose is not used. This means there cannot be absolute safety without zero exposure. A virtually safe dose is defined as the dose that corresponds to a certain acceptable risk that a population will develop a particular adverse health effect. "Virtual" safety has some risk attached to it. There can be several virtually safe doses depending on the shape of the dose-response curve in the low dose region. The economic ramifications can be considerable if there can be one or two orders of magnitude difference in the acceptable dose.

This work is expensive because rigourous procedures must be followed and large numbers of animals used. There are only very limited capabilities for this kind of work in Canada. We rely heavily on laboratories in the United States to produce the experimental data. Toxicologists in Canada reinterpret the data. For instance, in the case of the ban on saccharin, the data was

generated in the United States. Canadian toxicologists concluded a need for a ban existed while their American counterparts did not.

Many factors influence quantitative risk estimates, including:

(i) whether the substance being investigated reaches a susceptible cell and, if so, in what form,

(ii) how any initiated lesion develops,

(iii) age.

(iv) species,

(v) sex,

(vi) diet, and

(vii) statistical uncertainties such as extrapolation.

Normally, several sources of information have been used in setting standards for airborne substances:

(i) experimental human exposure,

(ii) human industrial exposure (usually acute cases due to accidental exposure),

(iii) human environmental exposure (public at large),

(iv) experimental animal exposure, and

(v) structural comparison of chemicals (this was based on the concept that the toxicity would be similar if the structure is similar - this is now known to be false).

2.5.7 Vinyl Chloride Risk Assessment Case Study

Theoretically, animal studies should reinforce information gathered through epidemiological studies of humans. Regulation of vinyl chloride can be taken as an example of the process. A cause-effect relationship was established between vinyl chloride exposure and the development of liver angiosarcoma. This link was discovered accidentally because a group of workers talking about their health found a high incidence of this rare tumour. Maltoni did the initial carcinogenicity bioassays on vinyl chloride. There was a report in 1970 of the occurrence of tumours in skin, lung, and bone of rats exposed to very high concentrations of vinyl chloride. Significant cellular changes were noted as a result of exposure to vinyl chloride. This indicated a need for an extensive investigation into the carcinogenic effects of vinyl chloride, particularly focussing on route of exposure, concentration, duration, and continuity. It took 7 years, 7 thousand animals and over a hundred thousand histopathological slides. That is why chronic exposure studies are so expensive and difficult to carry out. Note too that this was a single chemical exposure.

The range of exposure was from 30 thousand ppm to 1 ppm. The researchers were successful in establishing the angiosarcoma effect. They also detected a variety of tumours which by statistical analysis were not significant. However, this raised further questions. For instance, it was suggested that the experimental design might have affected the prevalence or absence

of certain adverse effects. The final conclusion of the research was that vinyl chloride is a multipotential carcinogen - it can produce tumours at a variety of sites.

Between 1958 and 1980 in Alberta there were two cases of angiosarcoma of the liver reported. Recent knowledge and reconsideration of these cases has led to some uncertainty as to whether they really were angiosarcoma produced by vinyl chloride. The average incidence is 1 case in 10 million.

The provincial government had to set a standard for vinyl chloride plants in Alberta. The question became whether the plants should be closed down because of carcinogenicity of vinyl chloride. The economic impact would have been very negative. An incidence of 1 case per 10 million people per year would suggest that for a plant with 200 workers exposed to 1 ppm, the increased number of angiosarcoma would be 1 case in 125 years. At 2 ppm, there would be one additional case in 90 years. This was an occupational exposure.

2.5.8 Formaldehyde Risk Assessment Studies

Formaldehyde has a very strong irritating effect on the nose. It is found in many building products, and in a wide range of other products as well. To do a risk assessment of formaldehyde would require taking into account exposures at home, at work, and in the natural environment from all sources. There are a lot of factors that can affect formaldehyde concentrations, including temperature, humidity, the source, its ventilation rate, duration

of emissions, and material age.

Between Ø and Ø.Ø5 ppm concentration of formaldehyde there are no reported clinical effects. This does not mean that there is no physiological change, such as alteration in enzyme activity, which is not expressed as a clinical abnormality. Between Ø.Ø5 and 1.5 ppm, neurophysiological effects can be detected. Eye irritation occurs between Ø.Ø1 and 2 ppm. 1ØØ ppm would be lethal. Indoor residential concentrations of Ø.Ø7 to 4.5 ppm have been found to be typical.

We have seen that the scientific considerations for any standard are going to be based on epidemiological work, animal bioassay, and risk assessment. A formaldehyde risk assessment was done by the US Consumer Products Safety Commission in 1981. It was based on a 198Ø-81 Chemical Industry Institute of Toxicology study. It was a chronic rat-mouse study. Inhalation exposures were 6 hours per day 5 days per week for 24 months (the average life expectancy of a rat). The range of exposures was 15 ppm to Ø ppm. It was found at 15 ppm that 95 rats had nasal cancer, 3 at 6 ppm and 2 mice at 6 ppm over the controls. A safety factor of 5ØØØ, which is sometimes used, would not allow for any exposure of humans based on these results. The researchers did not find any evidence for threshold. There was no epidemiology to support the findings of the laboratory work. A multi-stage model was used to generate the risk assessment. The upper estimate of risk was 15Ø cancers in 1.7 million people over the 5ØØ thousand homes that reportedly have been insulated with UFFI. This represents an

incidence of 1 in 10 thousand.

The assumption was made that individuals spent 16 hours per day in those homes 7 days a week, and that 1 ppm was the average concentration. Note that this was the upper estimate for incidence.

This study was redone for the Stockholm conference. At 1 ppm, the upper estimate was found to be 2.8 in a hundred. The lower estimate ranged from 1 in 100 thousand to 10 in 1 trillion. At 0.05 ppm, the odour threshold, we could see 1 cancer in 1 thousand people according to this study. That would be an epidemic. The point I am trying to make is that the results indicate either no problem or a very serious problem.

2.5.9 <u>Confounding Factors</u>

It is important to understand the concept of the confounding factor. This can be associated both with the exposure and the effect. Take, for example, molybdenum; it is known to be a cause of gout. Drinking is also known to be a cause of gout. Assessing the gout-causing effects of molybdenum in a population of drinkers would be complicated by this factor.

2.5.9.1 <u>The Healthy Worker Effect</u>

One has to make sure that the individuals who might show an effect have not been excluded from the analysis. This can happen if people terminate their employment before or after an effect shows up. This would mean that any study would have to follow up on those who had left. An alternative would be to use an opera-

tional definition of exposed which includes individuals who do not show the effect. For example, say a person is exposed if they have been working at a plant at least 6 months. Obviously, this is not satisfactory because the exposures have not been long enough.

2.5.9.2 Toxicological Information from Animals

Two steps are involved in the extrapolation of animal toxicological data to humans. It is necessary to extrapolate from the high dose effects into the low dose region. The problems with this have already been discussed. Secondly, it is necessary to convert from animal risk to human risk (e.g. of developing a tumour due to exposure to a certain dose). There is still considerable uncertainty in interspecies extrapolation.

2.6 Conclusion

In 1978, the US National Academy of Science stated that the carcinogenic risk for saccharin ranged between 22 in 100 and 1 in 1,144,000. I do not mean to belittle risk assessment, merely to show its limitations. This method is better than the safety factor method, which is merely grabbing a number out of the air.

The typical "sick building syndrome" is primarily one of a chemical irritancy. Dr. Ives Allery of the University of Pittsburgh has developed what I believe to be a very good animal model for investigation of such problems. He uses the physiological responses of mice to irritant chemicals in order to study respiratory responses to airborne irritants. The responses show

how adaptation occurs upon continuous exposure to a chemical irritant. As an example, reactions to exposures to sulphur dioxide (SO_2) could be used to generate a standard. LD5Ø occurs at 5Ø ppm for SO_2. This is the concentration at which there would be a severe irritation of the nasal mucosa. At 12 ppm one would expect to see a definite but tolerable irritation. At 1.2 ppm there would be a minimal effect. This method can be used to generate standards for sensory irritants.

In 1911 it was stated that

> "Public health is purchasable. Within natural limitations a community can determine its own death rate."

I suggest to you that in the indoor air quality area, because we do not know very much at this time, contaminants may or may not contribute significantly to the community death rate. Certainly, more money will be spent to find out if this is true. Only time will tell.

3. ISSUES IN AIR QUALITY INVESTIGATIONS AND RESEARCH

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It is expected that this paper will increase the awareness of students and professionals regarding difficulties which cloud air quality issues, and which may impede efforts to select and implement sound, practical solutions. It is not a technical research paper. It is a review of the problems and issues which may make assessment of questions regarding indoor air quality less straightforward than would perhaps be expected. My expertise is that of an environmental scientist, with a background in chemistry and biochemistry, who has worked on pollution problems and design issues affecting human health.

It is important to keep in mind four sets of actors which exchange questions, information, opinions and concerns: experts, patients and sufferers, the media, and the public(s).

The five sets of difficulties which will be discussed are:

(1) Suggestions that energy efficiency should be rejected as a design criteria for buildings because it is thought to be the cause of air quality problems.

(2) Research based on insufficient data, inadequate methodology, and poor problem definition. This may be leading to a polarization within professional groups, to extremes which uncritically embrace or reject indoor air quality as a real problem.

(3) Failure to distinguish exactly what kind of problem or set of problems is being dealt with. The

problems range from acute poisoning to issues of comfort.

(4) A host of confounding factors which will make it difficult and expensive, if not impossible, to prove cause and effect, especially when symptoms are not very specific.

(5) "Single factor fanatics" who have a tendency to ascribe all problems, and the solution thereof, to one issue. Their assertions are based, at least in part, on sound science, but are exaggerated, and grossly oversimplify the issues.

3.1 Energy Efficiency

It took more than a decade of hard work, on the part of those concerned about resource conservation, to establish energy conservation as a criterion for good building design. As is very often the case, the solution of one problem has revealed another set of issues. But the discovery of new problems does not mean that we should immediately discard the solution to the first problem.

It is not the least unusual that success in one area reveals or actually causes other problems. In spite of almost mind boggling advances in solving health problems in developed countries over the last two or three decades, life expectancy has not advanced in a linear, parallel fashion (1). The reduction of one risk factor reveals or is replaced by one or more new ones. No one has yet suggested that we reintroduce smallpox to reduce the number of people who die from AIDS or cancer. The introduction of seatbelts and the passage of legislation to permit enforcement of their use may be reducing the availability of organs for transplants because fewer eligible donors are ending up on a slab in

the morgue. It would not seem reasonable to discard the use of safety devices to improve our organ transplant record. Energy efficiency has contributed to major economic and employment difficulties due to the reduction in demand for natural gas, petroleum products and electricity. None the less, few if any have publically advocated the reintroduction of inefficient resource use as a realistic solution to economic and employment problems in the energy industry.

The use of energy efficiency as a design criterion is a positive step in conserving resources and improving the compatibility of technological societies with the natural environment. That we have uncovered apparently new, and at least on some occasions serious air quality problems, is not grounds for abandoning, or even compromising that advance. Initial efforts to solve indoor air pollution problems must start with efforts to stop pollution at the source(s). As with outdoor pollution issues, dilution is <u>not</u> the solution to pollution, at least in the first instance.

3.2 Data Base, Problem Definition and Assessment

I recall quite vividly a request on Calgary's CBC, which was basically a plea to turn in your father, or grandmother for alcohol abuse. The person making the appeal stated that they had no evidence that there were serious drinking problems in Calgary's senior citizens' homes. However, they were requesting Calgarians to turn in their friends and relatives who were in homes who might have drinking problems so that those concerned could use that evidence to go on and impose their solution to the

"drinking problem". Some reports on indoor air quality problems leave the same impression. Both the problem (adverse health effects due to poor indoor air quality) and the solution (increased fresh air circulation) are accepted without criticism, and efforts are made to gather data which will fill in the gap to show cause and effect.

When problems are complex and relationships tenuous at best, the quality of the data base, the rigorousness of the methodology, and the reproducibility of the results deserve even more than the scrupulous attention they normally require for good science (2). A review of literature on indoor air quality (3) has shown that the quality of research is often not good enough for the results to carry much weight. Base line data has been missing or inadequate, controls were not used, and methodological errors have left results ambiguous.

The following hierarchy of inquiries would seem to be a reasonable outline of how to proceed to investigate a suspected indoor air quality problem. Before simply increasing the fresh air supply, alternatives should be carefully investigated. The first step would be to ensure that the problem was really an air quality problem and not simply a problem attributed to air quality. Occupants might complain about air quality when the actual problem is stress, thermal discomfort or something else. It would be important to investigate the HVAC system to see that it was being used within its design limitations. As well, components of the system should be checked to see that they are functioning ade-

quately and that air is being circulated satisfactorily. A check on known pollutants that would cause acute or chronic health problems (carbon monoxide, carbon dioxide) should be carefully designed and implemented. Another element in a comprehensive assessment would be a systematic and thorough search of the building for possible sources which should be confined or eliminated. This would include machines, smoking, cleaning agents, solvents and other volatile chemicals, and gas appliances. One would then consider major changes in building design and operation. Consideration should be given to the isolation and venting of sources, or possible sources, of pollution. This would include isolated and vented areas: for smoking, if employees insist on smoking during working hours or breaks; for machines, which use volatile chemicals or generate ozone, and for storage areas for volatile materials. Only after everything reasonable has been done to eliminate sources, or possible sources of pollutants or irritants, should installation of heat exchangers and/or increasing of the fresh air exchange rate be considered.

3.3 Which Health Issues?

In some cases, dealing with indoor air pollution problems has been made more difficult due to poor, ill-defined diagnosis, or sloppiness in specifying what type of health or air quality problem is at issue.

For higher exposure levels which are generally industrial, standards are set for acute and chronic exposures which are known to cause problems. But discussions sometimes slip from description

of agreed-upon acute or chronic effects, to attempt to analyze very low level exposures without being explicit and methodologically exact about why and how the extrapolation was being made. On occasion, issues related to comfort are interspersed with discussions of acute or chronic toxicity without sufficient care being taken in the definition and application of the terms being used. In efforts to extrapolate from known acute or chronic effects to low level exposures, distinction should be made between those compounds which are known to accumulate in biological systems, including humans, (for example, heavy metals and refractory, nondegradable organic compounds such as dioxins, PCB's and pesticide residues) and those which are metabolized into harmless forms or for which there is no known mechanism for accumulation. One could be more confident about being categorical about rigid controls in the case of the former.

Allergies are understood although are not always easily diagnosed. The histamine reaction which an allergen causes is understood and the solutions to the problem can be provided by immunologists, at least in most cases. Immunization or separation of the allergic individual from the allergen(s) seems to be the alternative. Allergic responses can be produced by concentrations of materials below the capabilities of analytical equipment.

Clinical ecologists have identified "nonallergenic chemical sensitivities". Some of the best known of these are sensitivities to foods which cause a fast, sometimes violent and disgusting

reaction or set of reactions. I have good reason to believe that I have such a response to pineapple, and I know of a physician who thinks he reacts the same way. The mechanisms producing the reaction(s) are apparently unknown, but the symptoms are unmistakable. However, as a scientist I get uneasy when a wide range of symptoms are vaguely ascribed to unspecified "nonallergenic chemical sensitivities".

There are also legitimate concerns about low level exposures to pollutants which have a very long delay time between exposure and possible adverse outcome (carcinogens, mutagens, and possibly teratogens). These exposures would not lead to any identifiable symptom from short term exposure in an indoor air pollution episode unless victims were made aware of a possible exposure and then suffered from anxiety and stress.

The indoor air quality literature also addresses the issue of comfort. But the definition of comfort would seem to include a number of subjective factors. Furthermore, while comfort is important in terms of quality of life and employee productivity, its relationship to health is unknown.

The final category of diagnosis which should be mentioned is the "twentieth century disease" which appears to be a condition of allergies or chemical sensitivities to a very wide range of chemicals. It would not seem unreasonable to accept this diagnosis in those rare cases in which careful testing has eliminated specific, diagnosable problems, and in which are there persistent and consistent symptoms. In these unusual cases where detailed,

careful testing has eliminated any other possibility, rather extreme measures of isolation and extensive testing would seem to be in order. It has recently been reported that adverse stress has a significant negative effect on the immune system (4). Therefore, emotional stress at home or at work might lead to decreased resistance to illness which would increase stress, etc. possibly producing the start of a downward spiral in health and sense of well-being.

3.4 Confounding Factors

In cases where symptoms are relatively nonspecific (fatigue, lethargy, drowsiness, persistent colds and flu, etc) it would be necessary, but likely very difficult to identify and try to eliminate confounding factors. First it must be recognized that it may be necessary to do a rather detailed assessment of all of the workers' environments. This would include work place, home, recreation and exterior environments for exposures which might contribute to the problems. It might also be necessary to get detailed medical histories which would include the use of prescription and nonprescription drugs (both "over counter" and nonmedical uses), allergies and known sensitivities, diseases (diabetes, respiratory problems, hormonal imbalances).

I have recently been trying to assess a factor which complicates determination of health impacts of pollutants. It is the variability of individual biochemical responses to chemicals. There is a fairly wide range of responses to prescription and non-prescription drugs from no objective or subjective response on

one extreme to severe and adverse responses on the other. We know that individuals metabolize foods differently: a proportion of the population produces an unmistakable odour in urine from digestion of asparagus. The chemical composition of flatus, and where the red dye in beets shows up, is in part determined by individual body chemistry.

Knowing that we have a wide range of variability in response to and/or metabolism of drugs and foods, is it not likely that such variability exists with respect to responses to environmental insults? Therefore, in an exposed population, some may be sensitive and some not. The fact that not all an exposed population exhibited the same symptoms should not lead to the conclusion that there was no problem. It could be that 100% of the population which was sensitive was showing symptoms.

It must also be recognized that exposures to more than one environmental insult could produce additive or synergistic effects in at least some individuals. Symptoms might only appear when both components were present so that variability with exposure might be very complex.

Lifestyle factors should be investigated. Smoking would be an obvious factor. Level of fitness, regular exercise, and body weight for body type and age/sex cohort would be important factors. Determination of an optimum level(s) of stress (suffering from neither boredom nor tension) should be attempted. Personality conflicts or unhappy sexual relationships might also be contributing factors. Diet, including drinking water, should be

reviewed.

Finally, there is a host of environmental factors which might play a role under certain circumstances. Barometric pressure, positive and negative ion balance, winds, chinooks, seasonal changes, and winter darkness and cold have been identified as changing elements in the external environment which can affect mood if not health. Humidity and temperature, magnetic fields, wavelengths of light, exposure to other portions of the electromagnetic spectrum, noise and low level vibrations, and colour (decor) might be confounding factors in a complex environment of a sensitive individual. Plants (5) which produce pollen, dust and fungi, perfumes, deodorants, and body odours should also be checked as possible contributing factors.

The point here is not the provision of an exhaustive list of factors which must be investigated for any given indoor air pollution complaint. What I do hope to show is that for any problem which does not yield relatively quickly to analysis and diagnosis, the complexity may prohibit solution of the problem, or the work required to determine specific causes may be very substantial.

3.5 Single Factor Fanatics

In this final section, three types of single factor fanaticism will be mentioned. This is not done to lend them any credibility, but because professionals should be aware of them. They are easily sensationalized and so are attractive topics, at least for some factions in the media. Their simplicity has an appeal to frustrated sufferers of symptoms which have not been successfully treated, and for those who are unwilling to devote time and thought to possibly complex situations.

One single factor theory suggests that almost all environmental health problems are related to the relative abundance of positive and negative air ions (6). There is sound scientific evidence that under for certain portions of the population, changes in the negative/positive air ion ratio produces changes in the neurological hormone serotonin. However, most of the research on this topic will not stand up to scientific scrutiny. Therefore, while there is evidence that exterior or interior +/- air ion ratios may affect mood if not health (7,8,9,10,11), there is no conclusive evidence that it is the overwhelming factor in any given set of circumstances.

Recently I received a review of a book by an author who claimed that wind speed was a critical environmental health factor which could lead to such results as "fatal overstimulation" (12). I have not yet had an opportunity to read the book, but the claims made about it in the review would suggest that it would fall into the single factor fanatic category with those who believe that

winds produce +/- ion changes.

It has been proposed that the simple expedient of adjusting the exposure of electromagnetic radiation in the visible and near visible spectrum will solve all, or at least many of our environmental health problems (13). Once again, reproducible scientific experiments have shown that natural sunlight (or colour) has an impact on health and probably mood and general well-being. However, again it is not possible to validate the assertion that adjustments in the exposure of populations to specific wavelengths would be the single significant factor in improving the general level of health and well-being.

Finally, there is the "20th century disease", which some claim makes significant portions of the population, if not everyone, sensitive and/or allergic to many things, if not almost everything. However, sweeping claims that patients are allergic or sensitive to everything including water, and that addictions to food contribute to the problems must be met with some scepticism (14). Claims that such sufferers are even allergic to water (60% of your body weight) just do not seem credible. Such claims are clearly headline material, and may have an appeal to those who have not been able to eke out a satisfactory explanation for their problems. Those claims are also responsible for the fact that it is increasingly difficult to discuss such problems with the press or the public.

Each of these factors has some sound science behind it. However, the significance of the role of that particular factor, the

quality of the evidence supporting the case, the rejection of any other factors as contributing or complicating the issue, suggest that the exaggerated assertions must be rejected.

3.6 Conclusion

In conclusion, indoor air pollution is a problem and, a very serious one in some situations. However, on the one hand there appear to be exaggerated claims about the seriousness and the cause and effect relationships which are not supported by sound science. At the other extreme are those who, with a similar distain for rigorous science, reject the problem as insignificant. Claims that all energy efficient buildings have such problems are exaggerated. Where problems are identified, efforts to eliminate the pollutant(s) at the source should precede any compromise of a building's energy efficiency. The complexity of the issues, the number of possible confounding factors, and the distressing popularity of oversimplified analyses and solutions demand careful attention and painstaking work by the professionals involved.

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4. AN EPIDEMIOLOGICAL INVESTIGATION OF AN AIR QUALITY PROBLEM

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4.1 Introduction

As a vehicle to present some of the practical problems of investigating what might be called "occupational health complaints in the wild", I would like to describe a particular episode of this kind that I was involved in. One of the first points I would like to make is that if we are going to investigate health complaints, particularly when they have attracted publicity, multidisciplinary teams should be employed.

The case study I will present involved an epidemic of complaints at a school in Regina. It was a new school, with an air-tight envelope, and after a very short time the staff and students noted that they were suffering from eye irritation, feelings of fatigue, headaches, itching of the scalp, and other symptoms. The principal's description of the symptoms included the following: headache, tiredness, eye irritation, stuffy nose, blurring of vision, scalp itching, better at weekends, worse during the week with the return to school, not seasonal, and not related to allergies.

The first group of consultants called in measured substances such

as ozone, formaldehyde, and carbon monoxide. No offending substances were identified in substantial concentrations. In total, seven groups were called in to investigate the complaints before myself and my colleagues. No particular problem was identified, although the occupants continued to experience the symptoms described above.

The eighth group, of which I was a member, included a medical health officer (Dr. Hutchinson), an opthalmologist (Dr. Stead), an epidemiologist/biostatistician (Dr. Tan), and an occupational hygienist (Dr. Ken Yoshida). By the time we became involved, two years had elapsed since the initial complaints and the problems at the school had received quite a bit of publicity from the local media. In particular, there was some upset because experts were saying that there was "no problem", and the occupants of the building knew that there was a problem. I think that, as professionals and experts, we have to be very careful when people complain about their environments before we assert that there is no problem.

We could have made certain "herd" diagnoses about the McLurg School complaints. For instance, were the complaints just due to the publicity? Were the complaints due to mass psychogenic illness? The latter is very often enlisted as an explanation when there is an epidemic of complaints that cannot be explained. For example, a case of mass psychogenic illness reported in the literature took place in an electronics assembly plant. The symptoms included headaches, dizziness, light-headedness, weak-

ness, sleepiness, and nausea. They are not unlike the symptoms reported at McLurg. Another case was reported in a furniture assembly plant; symptoms included headache, bad taste, dry mouth, dizziness, and light-headedness. Both of these instances were identified as mass psychogenic illness because the investigators could not identify an offending vapour.

I do think that there is such a thing as mass psychogenic illness, but I think that it has a characteristic profile (some would dispute this) which involves more dramatic effects such as nausea and fainting. People think there is some serious problem and the symptoms are acute. However, this was one possible explanation of the problems at McLurg.

Another possible explanation might have been a physical illness or irritation (which may be two quite different things). The people at McLurg did not know whether they were suffering from an illness or an irritation. Parents were moving their children to other schools, and members of staff had left. Yet the morale in the school population as a whole was very good.

The problem could have been a known chemical substance, or an unidentified exposure. I would suggest that many irritants could be quite difficult to identify, such as possible emissions from new synthetic carpets or other new materials.

4.2 The Epidemiological Approach

We used an epidemiological approach to tackle the complaints. This involves looking for indicators of illness, taking illness in the broad sense, and relating them to time, place, person affected, and exposure together with a comparison with a control group. Assessing the characteristics of the symptoms involved determining:

(i) when problems were occurring (e.g. seasonally, by time of day, time of week),

(ii) where symptoms were occurring (e.g in one room, one part of the school, all over the city), and

(iii) who was experiencing the symptoms (e.g allergy sufferers, people with certain habits such as smokers, the young, the old, teachers, students).

Then we tried to determine what the occupants of the school were being exposed to, and to relate this to the pattern of complaints. We also had to establish a control group to which we could compare the occupants of McLurg School.

We established a few hypotheses and tried testing them against the experiences of the population at McLurg School:

(i) the hypothesis that there was an epidemic of complaints. (maybe there was not - just a few trouble makers),

(ii) the hypothesis that all occupants of McLurg School were equally affected,

(iii) the hypothesis that people who had symptoms of eye irritation had signs of disease in the eyes,

(iv) the hypothesis that the symptoms were related to a specific pollutant that we could identify, and

(v) the hypothesis that the symptoms were related to the ventilation system.

In addition to formulating the hypotheses, we wanted to characterize the illness - was it really what the papers said it was or was it something different? This task had two components, identifying the signs (what could be seen by the physicians) and the symptoms (what people reported). We tried to determine what parts of the body were affected - lung, skin, upper body, and so on. We tried to avoid bias. This involved random sampling of the population. We also got advice on our statistical approach at the study planning stage.

4.2.1 Epidemiological Methods Used

4.2.1.1 Questionnaire

We set up a questionnaire which included "distractors" - questions that had nothing to do with our hypotheses (see Figures 4.1 and 4.2, pages 68 and 69 respectively). For instance, it had been reported to us that people were complaining of stuffiness of the nose. So we put in "Does your nose get stuffy?"; we also asked "Do you get sneezing?" and "Do you get soreness of the nose?" to see whether people would agree to things because of mass psychogenic illness. Of course, most of the questions were related to our hypotheses.

	Column #
Name ______________ _________________	
Number [ ] [ ] [ ]	1-3
School [1] McLurg [2] St. Josephat [3] Al Pickard	4
Status [1] student [2] teacher [3] janitor [4] administrative	7
Age [ ] [ ]	8-9
Sex [1] male [2] female	10
Have you ever had asthma or hay fever? [1] yes [2] no	11
Do you smoke? [1] yes [2] no	12

	During the past week? If yes, ...	Have you had this during the past two days?	On most days, for as much as 3 months, during past school year (since Lab. Day, 1980)?	
Have you been bothered by:				
1. A headache...	[1] yes [2] no	[1] yes [2] no	[1] yes [2] no	13-15
2. Sneezing... (twice a day or more)	[1] yes [2] no	[1] yes [2] no	[1] yes [2] n	16-18
3. Unexplained tiredness...	[1] yes [2] no	[1] yes [2] no	[1] yes [2] no	19-21
4. Stuffiness of the nose...	[1] yes [2] no	[1] yes [2] no	[1] yes [2] no	22-24
5. Unexplained tiredness...	[1] yes [2] no	[1] yes [2] no	[1] yes [2] no	25-27
6. Soreness of the nose...	[1] yes [2] no	[1] yes [2] no	[1] yes [2] no	28-30
7. Itching of the scalp...	[1] yes [2] no	[1] yes [2] no	[1] yes [2] no	31-33
8. Stomach ache...	[1] yes [2] no	[1] yes [2] no	[1] yes [2] no	34-36
9. Cough (more than one or two coughs)...	[1] yes [2] no	[1] yes [2] no	[1] yes [2] no	37-39
10. Sore throat...	[1] yes [2] no	[1] yes [2] no	[1] yes [2] no	40-42
11. Blurring of vision...	[1] yes [2] no	[1] yes [2] no	[1] yes [2] no	43-45
12. Other eye trouble...	[1] yes [2] no	[1] yes [2] no	[1] yes [2] no	46-47
If not sure, check "no"	Go to Quest. 4 Sheet 2	Go to Quest. 6 Sheet 2		

Figure 4.1. Page 1 of McLurg questionnaire

- 2 -

		Column #
4. Have you had this in the past two days (yesterday or today)?	[1] yes [2] no Go to Quest. 5 / Go to Quest. 6	48
5. How did they feel? Did they feel...		
1. SORE	[1] yes [2] no	49
2. ITCHY	[1] yes [2] no	50
3. SANDY, SCRATCHY OR GRITTY	[1] yes [2] no	51
4. Have they been SENSITIVE TO LIGHT	[1] yes [2] no	52
5. STICKY? (Have they been stuck together in the morning?)	[1] yes [2] no	53
6. Other____________________	[1] yes [2] no	54
6. Have you seen our doctor about eye trouble in the past six months?	[1] yes [2] no	55
7. Who did you see? ________________________		
8. Is that doctor...............	your family doctor (GP) [1] an optometrist..........[2] an opthamologist........[3] don't know..............[4]	56
9. Do you mind if we contact that doctor?	[1] yes [2] no	57
0. Have you had a cold in the past week?	[1] yes [2] no	58
1. In the past week, have you noticed anything (else) wromg with your heath?	[1] yes [2] no	59
2. Are you wearing contact lenses? (If "yes", ask to remove before seeing doctor)	[1] yes [2] no	60
13. Have you worn lenses within the past 48 hours?	[1] yes [2] no	61

Figure 4.2. Page 2 of McLurg questionnaire

4.2.1.2 Personal Interviews by Physician

Personal interviews were conducted to determine medical histories for problems such as allergies.

4.2.1.3 Eye Examinations

The opthalmologist examined all the people complaining of eye irritation and a control group of non-complainers; this was done "blindly" (the examiner had no idea which group a particular subject was from and was not allowed to talk to them).

4.2.1.4 Study of Micro-environment

A cross-over experiment was conducted to study the ventilation system. One classroom had a separate ventilation system of a different kind, so for two days the students were shifted between the rooms with the two different systems. A questionnaire was administered after each shift without warning.

The environment was examined - vapours, ultraviolet light, humidity, and dust. Both sequential and concurrent tests were conducted to determine variations over space and time. In the case of dust, both respirable and non-respirable particles were examined. Particles were examined by both electron and light microscopy.

4.2.2 Controls

One control school, St. Jehosaphat, designed by the same architect and built at the same time, was located only a kilometer or two from the study school. The two buildings were almost identical. A second control school, called Al Pickard, was located about 7 kilometers away from the study school. It was about 20 years old and had a population similar in size to that of the study school.

All interviewing, other than the physician interview, was conducted by individuals hired through the local manpower office so that the consultants would not influence the respondents.

4.3 Results

To summarize, there was a significantly greater experience of headaches, unexplained tiredness, stuffiness of the nose, blurring of vision, eye irritation and itching of scalp.

Stuffiness of the nose and headache did not show a significant difference from the controls for the period of the week preceeding the questionnaire. Unexplained tiredness, blurring of vision and eye irritation showed significant differences from the control in this same period. The distractors were consistently denied, except for stomach ache. That single one could be accounted for by some local illness associated with food, or might actually have been an unreported symptom. It was evident that the teachers experienced symptoms more frequently than the students, although the population of teachers was quite small

(see Table 4.1).

Table 4.1. Summary of results on prevalence of complaints among teachers and students at McLurg School.

Percentages complaining (most days, for as much as 3 months, past school year)

	STUDENTS (174)	TEACHERS (15)
Headache	20%	27%
Tiredness	20	67
Stuffiness of the nose	17	47
Blurring of vision	16	53
Other eye trouble	20	67
Itchy scalp	15	27

There was no significant variation across classrooms. Therefore it did not appear to be an epidemic of suggestion emanating from one teacher. The crossover experiment indicated no significant difference between one room and another.

We did not find anything remarkable in the dust levels in terms of differences between one room and another. However, the sequential dust levels at Al Pickard School were lower on the weekend, while the dust levels at McLurg remained high on the weekends. One would expect the dust level to be high during the week due to the stirring up effects of activity, but not on the weekend. It turned out that McLurg School had a very active janitor who cleaned busily on the weekend as well as through the

week. He used porous bags, so that every time he vacuumed he resuspended the dust.

4.4 Review of Hypotheses

To review the hypotheses:

1. There did prove to be an epidemic of complaints at McLurg.

2. It turned out that not all groups were equally affected; the teachers were more affected than the students. On the other hand, the students seemed to be equally affected, and the number of teachers was small.

3. People with eye complaints showed no difference under physical examination from those who did not complain.

4. It was not possible to link complaints to specific pollutants. However, the symptoms were compatible with those attributable to large particle dust: eye irritation, stuffy nose, and itchy scalp. The headache and feeling of fatigue may have been secondary symptoms (e.g. caused by eye irritation and stuffy nose).

5. It was not possible to link the symptoms to the ventilation system.

The pattern of symptoms suggested an upper respiratory irritant affecting the conjunctiva and scalp, but certainly sparing the lung. This would be compatible with large particle dust. The

weekend dust persistence suggested resuspension by a vacuum cleaner with a porous bag. Action: install fine filter bag.

4.5 Conclusion

The chairman reported to the investigators that the epidemic of complaints had ceased. This was not a very methodologically sound way of determining that the problem as indeed solved, but the school board never asked the investigators to conduct a follow-up study.

In conclusion I would like to say that we must, when we are investigating such complaints, be sensitive to the concerns of the sufferers, for whom the problem may seem far from trivial. People do usually respond very well when an expert says "I don't know", but they do not respond well to "you are imagining this". As well, both health and environmental measurements are required in studies of this type.

4.6 Questions

O'Brien: Did you ever determine why the teachers had a higher incidence of complaints?

Markham: No, although we did find a white powder adhering to metal surfaces such as the blackboard frames. One of the investigating agencies had said that it was zinc oxide. Further investigation by our team suggested that the particles were from fibreglass insulating material used inside air ducts or detached from the binding material in the carpets (the latter by the

aggressive cleaning of the janitor). I found two articles in the literature about these short fibres causing eye irritation. These could have been picked up by physical contact between the teachers' hands and the blackboard, and thence by transfer to the eye. The human tearing system is incapable of rejecting these fibres.

Butler: What type of vacuum was used at the unaffected schools?

Markham: The offending vacuum cleaner was fitted with a textile bag. We determined that the short particles found on the blackboard would easily pass through this textile. Only large aspect ratio particles would have been captured. We recommended hospital type vacuum cleaners which are fitted with paper filters.

Love: What was the cost of the study?

Markham: The study cost $10000. We probably would not have started with such an extensive study if there had not been so much publicity and so many preceding studies.

N. Patterson: Did you find any links between humidity and the problem?

Markham: We did conduct an extensive literature search as part of the study. We found an article from Finland reporting that particle suspension from carpets increased at higher humidities due to reduction of the electrostatic attraction between the carpet and loose particles.

Patterson: Were the ventilation rates the same at all three

schools?

Yoshida: The older school had only a radiator heating system; that is, there was no ventilation system. The newer school had a variable volume air-conditioning system. The St. Jehosaphat school had the same type of circulation system.

5. A RESIDENTIAL BUILDER'S EXPERIENCE

Emile Rocher, P. Eng.
Dewinton, Alberta

This paper reviews the process that was used to provide a residence for a couple originally resident in Calgary, one of whom complained of adverse health effects attributed to airborne substances indoors. The author also offers some views on his personal experiences and thoughts on some issues of complaints about indoor air quality.

5.1 Construction of a Low Pollution Home

The woman for whom the residence was developed had a long history of medical problems that were eventually diagnosed by a clinical ecologist located in Michigan as being chemical sensitivities. The symptoms included a dramatic increase in metabolic rate - her pulse would increase to 160. This would alternate with periods of depression, fatigue, and nausea. Formaldehyde, and hydrocarbons in general, were particular offenders. There were no other apparent causes of the symptoms.

The couple spent approximately $100,000 renovating their existing dwelling in Calgary prior to deciding on a new residence. Some of the changes were cosmetic; they did not do anything about some of the major pollution sources - two gas-fired forced air furnaces and two gas-fired water heaters. Some of the materials

they introduced actually compounded the problem. For instance, ceramic tile was applied with a petrochemical base glue. After spending considerable amounts of effort and money, the clients decided to abandon this house and to start over again.

Since experiences with travel showed a diminution in symptoms with any change from southern Alberta, a site in the interior of British Columbia (vicinity of Kalamalka and Woods Lake, south of Vernon, north of Kelowna) was selected. It was a 32 acre parcel with two existing dwellings - a small guest house and a large bungalow. The site was just above the level of the fruit growing irrigated areas, and was judged to be high enough above what has become a persistent wood smoke smog in the local area.

There was some urgency in completing a dwelling, since the woman was pregnant and could no longer live in the house in Calgary. The clients wanted to be living on the new site within a month and a half of approaching the builder. Partly due to the short time available and partly for economic reasons, a decision was made to renovate the existing guest house. This structure was about 70 square metres in floor area, and in sound condition.

We (the builder) did not have the advantage of having the woman on or near the site to test her reactions to various materials, so throughout the construction I relied substantially on my own reactions since I myself have become chemically sensitive to a degree to a wide variety of building materials. It is not a very scientific approach to say that if something does not bother me it is not going to bother someone else, but it was really all I

had to work with in certain situations.

Several "technical fixes" had to be applied to the house from the bottom up. The house was set on a concrete frost wall with a crawl space which was contaminated with mold. The crawl space had an earth floor with deteriorated polyethylene covering. We applied new polyethylene and covered it with 100 mm of plain concrete. That did not solve the mold problem; we found that the walls of the crawl space were also contaminated. We coated them with a compound that is used for potable water systems ("Thoroughseal Cistern Coating"). That appeared to eliminate the mold problem. Ventilation in the crawl space was also increased.

Existing floors were linoleum tile over fir plywood, the tiles applied with a latex glue. The tiles came off quite easily since the glue was water soluble. Although the glue smelled a great deal while it was being removed, it stabilized after a couple of days. We decided that it should be protected from the possibility of water spill at some future date. Taped aluminum foil was placed over the fir plywood and oak strip flooring was applied in most areas.

I still do not know of a really satisfactory treatment for wood floors. Wood itself is usually tolerated by sensitized individuals. We opted for beeswax as a treatment, which itself has a very complex chemistry and I would be reluctant to recommend it as failsafe. We applied it hot and reheated it with a quartz heater that was rewired so it would operate in a horizontal position. The excess was scraped off by hand. Then we polished it

with a heavy commercial machine. By the time we were through with this I could not tolerate beeswax myself, but the woman appeared to tolerate this finish very well.

The beeswax has a lot of maintenance problems that may actually be beneficial. It is a great dust collector, and the only way to get the dust off is to scrape it off.

Ceramic tile with concrete based adhesive and concrete based grout was used to finish the bathrooms and foyer areas. The same finish was used on kitchen counter tops.

The degree of supervision required in this type of project is extreme. One case in point - I saw a truck pull into the yard. Fifteen minutes later I went into the house and found a tile applicator putting ceramic tile in the tub enclosure with a highly odoriferous petrochemical base glue. We spent two days getting that off.

The existing baseboard electric heating system was retained. It was not a great choice in terms of energy cost, but it was already there. Being old, it was likely that any materials used in its manufacture would have already substantially outgassed.

No positive ventilation was introduced, other than a 200 litre per second kitchen range exhaust. This had a very large hood to cover the whole of the range area.

The kitchen cabinets presented a particular problem. We used solid oak doors. The shelving, usually particle board which con-

tains objectionable substances, was made of solid core plywood. Arborite was applied to both sides of the plywood with 3M non-flammable contact cement. A water soluble mixture of stain pigments was used to stain the wood. This was sealed with shellac. In application shellac is probably one of the most offensive substances one could use; however, after two days I could stick my head in the cabinets, close the door as far as possible, and not detect any odours or gasses.

A lot of the choices of materials were risky in terms of possible adverse consequences for the occupants. For example, we should probably have used glass shelves in the cupboards instead of the arborite. This usually resulted from a desire on the part of the clients for a highly finished appearance. I think that some of the decisions were not correct ones as a result of this.

I tried to persuade the clients to accept plain plaster finishes for the walls and ceiling. We knew from experience that the woman could tolerate this material. For aesthetic reasons they required that paint be used although the couple had found no paint that the woman could tolerate. We spent a week on the telephone and learned that CIL had eliminated mercurial fungicides in their paints because they thought such paints would be outlawed. They instead were operating with "superclean" plant conditions to avoid spoilage of latex paint in the container. This seemed to be the best choice. In view of the time constraints between painting and occupancy, we set up a bank of portable floodlights. The lights were relocated at three hour

intervals and were left on overnight in freshly painted areas.

A chlorinated water supply by Culligan was used. A carbon water filter was installed on the water supply.

The results in the short term were gratifying. The woman found within a couple of hours of moving in that she could not tolerate some of the furniture that had been brought from Calgary - solid oak furniture with a urethane coating. It was the first time they had had this furniture in an environment that was not masking the emissions from the furniture.

The clients lived in the renovated guest house for a year. It seems though that we do not deal in absolutes in creating environments for chemically sensitized people. After a year the woman found that her tolerance to the first house was diminishing.

The same basic approach used in renovating the guest house was used in renovating the larger house. Again I felt that some decisions were made more for aesthetic reasons than in recognition of risks to the occupants. A positive ventilation system was not included. Hot water baseboard heating was installed, with a remote propane-fired boiler; this causes a problem when the wind direction is such that flue gasses are carried toward the house. Another problem that has surfaced is the insecticides that are used in nearby fruit growing areas that are carried on the wind. Wood smoke is also a problem from time to time.

In summary, the living quarters provided are an improvement over

what the clients had previously. The woman seems to be healthier. However, the whole exercise was extremely expensive for the clients.

5.2 Opinions on Air Quality Issues

I think one has to keep in mind when dealing with risk assessment that even if the number of people severely affected is small, the consequences for those people are very grave, especially in economic terms.

I know many people in Alberta now who have been going through similar problems with air quality. Some of them are at the end of their financial resources and are so severely affected as to be unable to earn a living.

The role of the clinical ecology movement has been pretty controversial. Some of the comments made today show that. Any time someone challenges the existing way of doing things there are going to be people who feel threatened. In some cases it is because it will force them to learn a whole new set of ideas and to apply methods that they have no knowledge of.

It would not be fair to say that all the clinical ecologists I have met impressed me as having good answers. However, one can make such a statement about any group of professionals. As a group they have impressed me more than any professional group I have had anything to do with in the past ten years. I think it is important to remember that these people were trained in con-

ventional medical programs. Yet, they have tried to approach problems of health in a broader way.

The international clinical ecology group held their annual conference in Banff in 1983. To my knowledge there was one practicing physician from Alberta in attendance. The reason he was there was that shortly after moving into a new house his wife experienced a host of inexplicable symptoms. The husband refused to believe that it was psychological. Ninety times out of 100 she would have been given valium and relegated to a large group perceived as hypochondriacs. The husband now has a very different practice. He claims that he always had a core 20% of patients that he could not help; he now feels that he has been able to help most of these people through the methods of clinical ecology.

Dr. Rae, a clinical ecologist from Texas, claimed during a course here two years ago that he believes that 80 percent of the population is adversely affected to some degree by indoor air pollution. Now I do not think this means that the majority of these people require the assistance of clinical ecologists.

The reason that I have become particularly interested in this is that both myself and my infant daughter seem to have chemical sensitivities. I have been building energy efficient air-tight housing for some five years now. In the second year of this work, I began to experience chronic fatigue. I subsequently attributed some of these symptoms to food and chemical intolerances. I have learned to avoid problem substances; I always

wear a gas mask when I am doing any type of interior finishing work.

Our daughter's problems were the spark that really led me to pursue the subject of indoor air quality vigourously. There were no indications of any abnormalities at birth. We moved into a new home when she was 18 months old. The house was unfinished for financial reasons - no carpets, bare particle board on the floors. It was a conventional house - it leaked like a sieve. She began to develop peculiar behaviours; she would lie on the floor for hours at a time. We were unable to get her interested in things. We took her to doctors who were unable to find any problems.

She began to have what has since been diagnosed as temporal lobe epileptic seizures. Prescribed medication did not seem to work. We began to look at alternatives. We found allergies to a wide range of foods. She reacted, sometimes with seizures, to a selected group of chemicals, although not reliably. Occasionally she would be standing at a bus stop and the fumes from the bus would be sufficient to cause a brief seizure. More typically the symptoms would persist for days. We still do not have all the answers, although we are making progress. She is attending a normal school in a special education class. Last year the classroom was repainted and new carpets were installed which has led to a recurrence of symptoms.

The sensitivity to a broad range of substances makes preventative measures very difficult. On average, clinical ecologists would

claim that if one is allergic to foods at all, one is allergic to at least seven.

I do not have much confidence in the possibility of dealing with the problems of the sensitized individual through the technologies of environmental control. Technology can be used as a temporary measure to gain time in which to analyze the sufferer's problems. Chemical loading has to be viewed as another addition to the basket of stress.

I do not think any of us are immune to chemical sensitivity. There are certainly high risk groups that are more susceptible - young children because of their high metabolic rate, people with other illnesses, old people. However, 10 years ago if you asked me what bothered me I would have said "nothing". I could eat diesel exhaust fumes and love it, but things change.

One thing I would like to draw attention to is the recent trend among many clinical ecologists towards the implication of yeast infections, particularly candida albicans, with the onset of broad chemical hypersensitivity. Crooks has an excellent book on the topic, <u>The Yeast Connection</u>.

5.3 Questions

Mayhew: Do you see any movement in Canada toward identifying the chemical composition of building products as is being done in the United States? Do you see the elimination of known pollutants from building products?

Rocher: Some of the most encouraging work is coming from the Prairie Branch of the Division of Building Research of the National Research Council of Canada - the same people who developed the concept of the super energy efficient house. I think that we are going to see a whole new set of standards for building materials.

It is probably appropriate at this time to talk about ventilation rates. The number that has been suggested (Ø.5 air changes per hour) does not have an extremely rigourous basis. The materials included in the interior of a house and varying lifestyles, among other factors, make it difficult to set air quality standards simply by air change rate. I think we need to educate the building industry and the public as to what is required to provide a safe environment.

I think that the report produced by Bruce Small, Indoor Air Pollution and Housing Technology, with the financial assistance of CMHC is a very valuable guide, especially in terms of the problems of highly sensitive individuals.

6. ENVIRONMENTAL CONTROL IN LARGE BUILDINGS

Mr. Jim Lowden, P. Eng., The Mitchell Partnership
Calgary, Alberta

The Mitchell Partnership are consulting mechanical engineers. Services dealt with by mechanical engineers include fire protection, plumbing and drainage, heating, and air-conditioning. Our practice includes all sorts of buildings, but the heart of our business in the past 10 or 15 years has been large office buildings.

The notion of "sick" buildings is new to the mechanical engineering profession. I have grouped the things that people complain of into two groups: those having to do with thermal comfort, and those having to do with contaminants in the air. Historically, the mechanical engineer has been mainly concerned with the provision of thermal comfort in buildings, and this has shaped the mechanical design of buildings. Often, when lay people state that a building has an "air quality problem", they in fact mean that it is uncomfortable. I will first review the basic aspects of designing for thermal comfort, and then discuss how some contaminants are dealt with. I will also discuss the relationship between cooling and ventilating systems.

6.1 Designing for Thermal Comfort

ASHRAE, the American Society of Heating Refrigerating and Air-conditioning Engineers, is currently the most influential group in establishing guidelines for comfort in the indoor environment of office buildings. ASHRAE recommends temperature, humidity, and air movement rate ranges that are determined by research to be acceptable to the majority of people. These guidelines take into account amount of clothing (which affects rates of body heat loss) and activity level (which affects body heat production).

The recommended temperature range for winter clothing levels is 22 to 23.5 degrees, with a desirable minimum relative humidity of 30%. The suggested maximum acceptable rate of air flow is 0.15 metres per second (m/s), which is barely perceptible. The summer temperature range is 23 to 26 degrees with 24.5 degrees being preferred. The recommended upper limit for humidity is 50% in summer, with 0.26 m/s as the maximum rate of air flow.

There are comfort tradeoffs - people will accept a higher humidity if the temperature can be reduced, or a higher temperature if the humidity can be reduced. ASHRAE charts quantify such tradeoffs. ASHRAE has also developed an effective temperature scale which incorporates all of the factors bearing on thermal comfort, including amount of clothing, rate of air flow, temperature and humidity.

A problem faced by mechanical system designers in Calgary is that at 25% indoor humidity condensation will occur at the 1% design

temperature (the low temperature that will be exceeded 1% of the time) due to heat transfer through even double pane glazing. This means that 30 percent relative humidity (the ASHRAE lower level for comfort) is virtually unattainable with double pane glazing due to the large amounts of water that would be deposited on windows.

Another factor in comfort is stratification. It has been determined that in a stagnant space, a temperature difference of 1.3 degrees will exist per metre of elevation change.

Temperature variation over time also affects comfort. The maximum change that people will find comfortable is 0.5 to 1.0 degrees Celsius per hour.

Another factor is radiant conditions. This is sometimes referred to as the "cold wall" effect. If a person is sitting next to a wall that differs by more than 10 degrees Celsius from the ambient air temperature, they will usually be uncomfortable. For the ceiling, the number is 5 degrees Celsius. Most people become uncomfortable if floor temperatures move beyond a 18-29 degrees Celsius temperature range.

6.2 Contaminants

Until recently, professionals dealing with environmental control in buildings were not concerned about contaminants other than carbon monoxide and carbon dioxide. Airborne substances causing odours have also been a long-recognized design issue.

6.2.1 Carbon Dioxide

One might expect to find 300-350 ppm of carbon dioxide outdoors. An acceptable indoor concentration of 600 ppm will elicit very few complaints. 600-800 ppm will result in several complaints. Levels over 800 ppm will generate a large number of complaints (1). Sometimes plants are added to environments to alleviate stuffiness attributed to excessive concentrations of carbon dioxide. However, one would require a forest to make any substantial difference.

6.2.2 Carbon Monoxide

Outdoor concentrations of carbon monoxide range from 1 to 2 ppm. The average person exhales 14 ppm; smokers, 35. 400 ppm is enough to make a person comatose.

6.2.3 Odours

The most common complaint of building occupants is "staleness" or stuffiness of spaces. The second biggest complaint is tobacco smoke. The contents of buildings are also sources of odours.

Food odours are very difficult to deal with. The only real solution is to contain and vent fouled air from kitchens and other odour producing areas.

6.2.4 Historical Response to Contaminants

Ventilation is used to keep carbon dioxide and carbon monoxide to acceptable levels since there are not any commercially viable systems for eliminating or converting these gasses.

There are very few codes that govern air quality in Canada. The Ontario Building Code requires that washrooms have a ventilation rate of 23.5 litres per second per fixture. The National Building Code regulates carbon monoxide levels in parkades. It requires that 50 ppm not be exceeded and that an alarm be sounded when 100 ppm is reached. The difficulty is locating the sensor to monitor this condition, since concentrations will vary widely within the space. The Ontario Code requires 23.5 litres of air per second per parking stall, or that levels be kept below 50 ppm. Note that all figures referring to air flow that follow refer to <u>outside</u> (<u>fresh</u>) <u>air</u>.

To maintain 1000 ppm in a typical office, the minimum ventilation requirement would be 1.4 litres per second (outside air) per per-

son. To maintain 600 ppm, 3.3 litres per second per person is required (here smoking is not permitted). These rates are much lower than is normally provided in a contemporary building.

The ASHRAE standard for ventilation is 2.4 litres per second per person for nonsmokers and 7.0 litres per second per person for smokers. Public Works Canada requires 7.0 litres per second per person regardless of the concentration of smokers. We have found that for odour control 4.7 to 14 litres per second/person are required.

The reason for the large range is variation in activity, contents, and concentration of occupants. At the design stage, there is also considerable uncertainty as to the future concentrations of occupants and the percentage of smokers. Most designers would assume a concentration of occupants of 1 per 9 square metres. That is pretty well the upper limit of density for indoor space use in an office setting. The average is more like 14-23 square metres per person. This translates to 0.5 to 1.3 litres per second per square metre office space.

Ideally one might use a sensor, as for carbon dioxide, to regulate air flow. Again, one would encounter the problem of locating the sensor.

6.2.5 Problems with Natural Ventilation of Large Buildings

Occupants of buildings commonly desire operable windows because this is seen as a means of controlling their own air quality and thermal environment. Operable windows are always an issue in designing a building. The reasons for not having operable windows in commercial buildings include:

(i) the outside air is sometimes polluted,

In the case of a large building, the point at which fresh air is drawn into the building may be considerably cleaner than the air that would be drawn in through some windows.

(ii) stack effect,

A warm 24 degree building sitting in a colder ambient environment acts like a chimney. The air contained within the building will attempt to rise through the building and force its way out through the top.

(iii) opened windows make it impossible to maintain the balancing of the ventilation system (controlling the supply and return of air to various spaces),

(iv) dust and insects can enter opened windows,

(v) security,

(vi) occupants may forget to close windows when they leave, resulting in weather or other damage later,

(vii) moving parts always require more maintenance,

(viii) more noise will be admitted through the building envelope if windows are opened,

(ix) opened windows can produce undesirable smoke migration in case of fire,

(x) opened windows result in loss of humidity control, and

(xi) openable windows cost more.

6.3 Cooling Requirements of Large Buildings

Mechanical ventilation systems are also used to cool large buildings. Large buildings have limited surface area, which means that heat generated by solar radiation, people, lights, and miscellaneous equipment must be removed by mechanical means. The lighting load is usually constant through the day, while other loads are variable. The cooling must be controllable to respond to this variability.

The requirement for cooling air is a function of the difference in temperature between the temperature desired for the space and the delivery temperature of the cooling/ventilation air. Comfort requirements limit the temperature at which air can be supplied. The supply air, because of this, cannot be more than 1Ø to 14 degrees below the space air. Given this constraint, the volume of air required for ventilation is usually quite a bit smaller than the volume required for cooling. Thus, the ventilation component is generally only a small fraction of the air being moved through the spaces in a building.

Occupant discomfort in perimeter areas of buildings almost always results from excessive solar heat gain. Any problems with volume of air circulated usually occur at the interior where volumes of air circulated are smaller.

Until the mid 6Ø's, systems were used that delivered a constant volume of air, and varied the temperature in response to the

cooling requirement. The adjustment in supply air temperature for comfort was achieved by reheating air at the delivery point. This was not very energy efficient. When energy costs escalated, variable air volume systems were adopted. Rather than adjust the temperature of the air, the volume supplied was adjusted in response to varying cooling requirements.

To be fair, prior to advances in our understanding of air distribution, variable volume systems were inferior in terms of providing comfort. Rather than a small number of large diffusers, a large number of small diffusers are required for satisfactory distribution of air with varying supply volumes. Adoption of this approach has resulted in acceptable performance of variable volume systems.

Problems with variable volume systems have arisen where temperature alone controls volume. It is evident that in a net heating situation (as on the north edge of a building when the outdoor temperature is lower than the indoor temperature), the air supply would shut off completely. It is essential that the air supply required for ventilation purposes be maintained in such situations. The problem of reduced cooling air supply has been compounded by the reduction of lighting levels as an energy conservation measure. Reduced lighting leads to lower cooling loads, and reduced air supply rates. Supply air temperatures should be adjusted upward (less cooling per volume of air supplied) to maintain volumes of air supplied. Currently, one may find supply temperatures as high as 16 degrees Celsius. In some cases reheat

coils have been added to air supply terminals to keep supply temperature and supply volume up. These reheat coils differ from the earlier versions in that they do not have the capacity to temper the maximum volume of air. These coils only switch on after the terminal reduces flow to a minimum rate.

Another development is the fan-powered variable volume terminal. This is a fan unit located in the ceiling space of the room which circulates a constant volume of air. Attached to it is a variable air volume terminal which varies the amount of cooling. We are currently specifying this type of system for a new school to be built in Fort McMurray.

Local exhaust fans are being installed in selected locations such as conference rooms to ensure adequate ventilation. Another measure has been shutting off the return air vents from perimeter offices, forcing the air to travel via doors to the core of the building. This increases ventilation at the core of the building.

It is important to realize that all of these responses require a direct knowledge of the environment to be modified: how the occupants use the space, what systems are in the building, how they have been modified and so on.

In summary, here are 7 ways the mechanical designer can help to avoid "sick building" syndrome:

(i) location of fresh air intake to avoid loading docks, polluted streets, kitchen and parkade exhausts, and other such areas,

(ii) controllers should be set so that there is an acceptable minimum level of ventilation in all spaces during hours that they are occupied,

(iii) good air filtration - use of appropriate, well-maintained filters of high quality,

(iv) good air distribution - avoiding stratification and stagnation,

(v) flexibility for future changes - for example, accommodation of the heat from personal equipment such as computers,

(vi) containment of contaminants as they are generated - for example, kitchen odours and blueprint machines, and

(vii) continual consideration of the comfort of the occupant in the course of designing.

6.4 Questions

Leckie: How would increasing the air-tightness of the envelope of an office building affect the performance of the mechanical ventilation system?

Lowden: It would lower the neutral pressure zone of the building (the point at which there is a crossover from negative inside-outside pressure differential to positive inside-outside pressure differential - the differentials being due to stack effect, which is discussed above). Rebalancing of the mechanical systems would likely be required. The balancing should be checked to see if this is necessary. For instance, infiltration would be reduced at the bottom of the building in the heating season; less heating would be required in these areas after sealing.

Question: It is quite common now to shut off ventilation systems

when buildings are unoccupied in order to conserve energy. Should the buildings managed this way be purged by running the ventilation system with the outside air dampers open for an hour or two before occupants return?

Lowden: Yes, this is particularly true in the case of new buildings.

Love: This raises the question of the quality of the outside air being used to purge the building. For instance, during rush hour, vehicle fumes may produce high levels of pollution in downtown air.

Lowden: The products of combustion from internal combustion engines - carbon monoxide and carbon dioxide - are produced close to ground level. This would suggest keeping the fresh air intake up as high as possible.

Question: Have any studies been done of the relative costs of shutting systems down versus continuous operation?

Lowden: Yes. I think the general rule is that 8 hours is the minimum setback time to achieve monetary savings in a typical office building. This will vary depending on characteristics of buildings such as mass, surface to volume ratio, and insulating value of the enclosure.

W. Patterson: I have observed that partitioning of spaces originally set up for open landscape can adversely affect circulation. Is there any way of designing ventilation systems to anticipate

such changes?

Lowden: This is a real and common problem. The costs of providing total flexibility with conventional systems would be extremely high.

Russell: I was recently informed that a large company in the air-conditioning business that is now working with furniture manufacturers to create work-place modules which will include facilities for lighting, computer terminals, communications and self-contained micro-climate facilities. It will be interesting to see how these systems develop.

Lowden: The electronic office is bringing about some radical changes in mechanical system design. For instance, our Toronto office is now working on a project in which every story of the building has raised floors. This office building, for Olympia and York, is located on York Mills. The space under the raised floor will be the supply air plenum, maintained at slightly positive pressures. The air distribution terminal is a propeller fan that is a drop-in floor panel. The fan operates at variable speeds and is controlled by a thermostat which is an integral part of the related desk or work station. The advantages of such a system are, for instance, that if the fan is causing a draft, it can be easily relocated. It is estimated that the increased cost is less than 5% because no suspended ceiling is required. Light fixtures, other than those built into the furniture, are portable and sit on the floor.

6.5 References

1. "Occupational Health in Ontario", Ontario Ministry of Labour, Occupational Health and Safety Division, Volume 4, No. 4, October, 1983.

7. FEDERAL GOVERNMENT ACTIVITY

Mr. Peter Russell, P. Eng., Research Division
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This talk is intended to provide a sampling of activities of federal government departments that are related to indoor air quality. It is impossible, in the time available, to exhaustively review the work underway. The following will at least indicate some of the directions that are being taken.

There is an interdepartmental committee of the federal government which has been struck to deal with indoor air quality. This committee answers to another committee titled the Interdepartmental Committee on Toxic Chemicals which operates within Consumer and Corporate Affairs. Apart from Consumer and Corporate Affairs, members of the subcommittee on indoor air quality include Energy Mines and Resources Canada, Environment Canada, Health and Welfare Canada, Indian Affairs and Northern Development, Labour Canada, Department of National Defence, Public Works Canada, Department of Supply and Services (which operates the Canadian General Standards Board), Transport Canada, Treasury Board, the Atomic Energy Control Board, Canada Mortage and Housing Corporation (CMHC) and the National Research Council. Other departments, such as Agriculture Canada, are involved in a secondary role. This subcommittee was struck last year. It is intended to coordinate the activities of government departments relating to

air quality, and to report to Cabinet.

Two weeks ago the subcommittee organized a workshop which brought together about 3Ø experts from across the country, as well as members of the subcommittee. A major conclusion of this session was that indoor air quality should not be considered in isolation from other building science issues. For instance, foundation cracks in low rise housing are a problem in certain areas of the country, such as Winnipeg. Of 18 cities across Canada that were surveyed, Winnipeg had the highest proportion of homes that exceeded a particular radon criteria. The admission of radon is related to the foundation cracks. Repair measures evaluated by a consultant to CMHC would appear not to be cost-effective based on structural considerations alone. Perhaps the repairs would be justified if the added factor of radon leaks through cracks were also taken into account.

CMHC has arranged occasional informal meetings of representatives from various government agencies to improve interdepartmental communication about ongoing work in indoor air quality.

Energy Mines and Resources (EMR) Canada has recognized that air quality and ventilation are intimately related to energy conservation in buildings. Research on air quality and ventilation is one research priority within the energy conservation research supported by EMR.

7.1 Activities of Federal Departments, Corporations, and Agencies

7.1.1 Health and Welfare Canada

Health and Welfare is involved in a federal-provincial working group that is attempting to establish guidelines or standards for 18 pollutants and groups of pollutants. Those guidelines might be available next year. A similar process was followed in establishing criteria for drinking water, and worked quite successfully. The group intends to produce a popularized version of their findings which will assist homeowners in improving air quality in their homes. Health and Welfare Canada is also conducting some survey work on air quality in housing. Similar work is also being carried out by CMHC, the National Research Council, and Energy Mines and Resources. It is hoped that larger scale surveys will be arranged in future through inter-departmental cooperation.

The research staff at CMHC are engineers. We very clearly see the need for cooperation with other disciplines in investigating indoor air quality issues. For instance, Health and Welfare Canada will play a major role with regard to toxicological aspects of air quality work.

The 1979 radon study, alluded to above, involved obtaining "grab" samples from 14,000 homes across Canada. It has raised a couple of questions. It cannot yet be explained why the concentrations of radon in Winnipeg houses are so much greater than elsewhere in the country. No correlation could be found between radon levels and cancer incidence because smoking has acted as a confounding

factor. An epidemiological study is being conducted in two cities to determine whether a link between radon levels and cancer exists. This is a very good example of a building science problem that requires the expertise of several disciplines.

7.1.2 Public Works Canada

Public Works has considerable expertise in the area of large buildings, I will not go into detail since Dr. Kayser will be discussing some of this work.

7.1.3 Energy Mines and Resources

There are two distinct groups at Energy Mines and Resources (EMR) Canada involved in the air quality area. Canadian Combustion Research Laboratories, of EMR, is working with CMHC on problems related to combustion. Secondly, EMR's Building Energy Technology Transfer group, which operates the R2ØØØ program, is measuring contaminants in all R2ØØØ homes. These include formaldehyde, radon, carbon monoxide, carbon dioxide and other chemicals. They are also examining the potential for backdrafting. A number of studies which they are doing that should be of interest are just reaching completion.

7.1.4 Consumer and Corporate Affairs

Consumer and Corporate Affairs have a mandate to deal with appliances such as kerosene heaters and portable air filtration devices. They also deal with problems such as the outgassing of materials such as particle board. They have reported that they have seen considerable improvement of that product over the past 12 months. Consumer and Corporate Affairs also operates the UFFI Centre, which is dealing with the clean-up of UFFI insulated homes. Some specific areas of research include the use of air filters to scavenge formaldehyde and immunological testing of asthmatic persons. The latter involves not only formaldehyde but also other products of UFFI off-gassing. Their research program has also included heat recovery ventilation systems. They are concerned not only with the product, but also with its correct installation and operation.

7.1.5 National Research Council

Some of the National Research Council's activity in indoor air quality (in particular, the investigation of UFFI off-gasses) has been curtailled due to funding reductions. A small group will be concentrating on the better understanding of the science of ventilation.

7.1.6 CMHC

CMHC has sponsored a number of studies and the production of a number of reports, some of which are still in draft form at this time. A list of these publications is provided in the final section of this paper (titled "References").

7.2 Non-Governmental Organizations

The work of groups other than government departments also deserves mention.

7.2.1 Canadian Standards Association

The Canadian Standards Association has various groups working on indoor air quality related issues. One is concerned with chimneys, another with controlled ventilation. The Canadian General Standards Board is trying to set standards for air-sealing. For instance, one task is to identify the ventilation requirements that an air-sealing contractor should meet. This includes definition of tests to determine that this requirement has been met. ASTM has recently held a meeting on standards for measuring indoor contaminants. ASHRAE Standard 61-82 on minimum ventilation rates for residential occupancies is a very valuable document; however, as soon as it was completed, ASHRAE struck another committee to consider revisions.

7.2.2 Canadian Home Builders' Association

The Canadian Home Builders' Association (CHBA - formerly HUDAC) has a task force on controlled ventilation. HRAI (The Heating Refrigerating and Air-conditioning Institute) are working on heat recovery ventilators - the improvement of installation practice and design methodology of residential ventilation systems.

7.2.3 Canadian Electrical Association

The Canadian Electrical Association has contracted out research to consider problems of ventilation in electrically heated houses.

7.2.4 American Pollution Control Association

Lastly, the APCA (American Pollution Control Association) has organized an April conference on the subject, to be held in Ottawa.

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8. CMHC ACTIVITY

Lorne Finlay, Project Implementation Division
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8.1 Introduction

Two divisions of the Canada Mortgage and Housing Corporation are undertaking and sponsoring work on air quality in buildings. These are the Research Division and the Project Implementation Division. This paper will cover the work of each division separately.

8.2 Research Division (Peter Russell)

Air quality related research at CMHC falls into three categories:

(i) ventilation (including ventilation guidelines and their evaluation),

(ii) combustion (including carbon monoxide problems in housing and studies of flues), and

(iii) moisture (including studies of moisture troubled houses, moisture sources in housing, and studies of wall performance).

All of these efforts relate to the design of ventilation systems. In my earlier review of federal government activities, I listed some of the documents that have been produced by or for CMHC on air quality. Some significant projects that the research division has sponsored or undertaken in these areas are described below.

8.2.1 Ventilation Guidelines

The document, Guidelines for the Design and Installation of Residential Controlled Ventilation Systems, which was prepared for HUDAC (now CHBA or Canadian Home Builders' Association) is a good example of how not to do something. CMHC managed an evaluation of these guidelines. Initially the concept seemed excellent. The guidelines sum up what a lot of people are looking for. They were written under the direction of a CHBA (then HUDAC) task force. It purports to tell the building contractor about the issues and their resolution. However, when CMHC contracted with a consultant to assess the applicability of these guidelines, they were found to be of questionable value. Five houses in Ontario and three in B.C. were constructed by contractors who attempted to follow the guidelines. Two problems were identified. Firstly, the audience was not carefully identified. Secondly, an interest and knowledge level was assumed that was not born out in reality. It was too detailed for the general contractor and insufficiently detailed for the heating and ventilating contractor. Secondly, the ventilation rates recommended in the document were based on ASHRAE standards (5 litres per second per habitable room plus adjustments for bathrooms and kitchens). This criteria was impossible for contractors to check. The only methodology they have is the HRAI (Heating, Refrigerating and Air-conditioning Institute) procedure for sizing of heating systems to distribute heat through a forced air system. It is extremely difficult to superimpose on that a requirement for a continuous ventilation rate. It seems obvious

in hindsight, but was not obvious to the proponents of the project when it was initiated. Another problem is the lack of a readily usable technique to verify that the requirement is being satisfied.

8.2.2 Air Flow in Housing

Twelve houses in Apple Hill, homes west of Ottawa, were studied to determine patterns of air flow - both from inside to outside and from zone to zone within the house. All the houses were built by the same contractor. Although the designs varied, they were very similar and of the same standard of construction in terms of features such as air-tightness.

A perfluorocarbon tracer gas technique, developed at the Brookhaven Research Laboratories, was used. This involves putting two capsules in each zone of the house to be tested. One emits a tracer gas and the other collects it. After a period of 4 weeks the capsules are returned to Brookhaven for analysis. By this technique, infiltration and exfiltration were determined for the basement and the main floor, as well as the interzone movement of air.

Radon levels were also measured. A number of methods of measuring radon were employed. The Radiation Protection Bureau of Health and Welfare Canada collaborated in the latter study.

It might be anticipated, given the stack effect that exfiltration would be greater in the upper story than the lower. However the exfiltration from the main floor was an order of magnitude

greater than from the upstairs floor. This shows that one cannot make universal assumptions. These houses were built particularly air-tight on the second floor. This resulted in unusually low exfiltration at the upper level. Readings were taken at three times of the year - November-December, January- February, and March; there was not much variation in the results from one time period to another.

This technique can show things that may not bear out conventional assumptions about the performance of housing. One current problem is that Brookhaven has the only laboratory capable of doing the analysis. There is a long backlog in processing samples. It is also an expensive technique to apply on a large scale at the current time.

8.2.3 Carbon Monoxide Survey

I will briefly discuss a survey conducted on carbon monoxide. This survey was carried out to identify episodes between 1970-81 of a carbon monoxide hazard being identified in housing, whether or not actual sickness or death resulted. It was very much a biased sample since records are not generally kept on this. We did manage to document about 300 instances over that period. It was concluded that the prime causes of carbon monoxide hazards were equipment problems (see Tables 8.1 and 8.2 on page 114). The percentages add up to more than 100 percent because usually it was a combination of factors that resulted in a hazard.

Propane refrigerators were found to be particularly lethal.

Table 8.1. Major contributing factors to carbon monoxide hazards.

Contributing Factor	Percent of Episodes in Which Implicated
1. Equipment problems	46
2. Blocked chimneys	31
3. Backdrafting	25
4. Lack of understanding	24
5. Recreational setting	18

Table 8.2. Minor contributing factors to carbon monoxide hazards.

1. Air-tightness of envelope
2. Inadequate exhaust of secondary combustion appliances
3. Competing ventilation
4. Weather conditions

These are typically used in cottages which are not serviced by electrical power systems. People did not recognize that these refrigerators were, in fact, combustion devices. The hazard was greatest in cold periods when cottages were used, yet kept closed up.

We do not hold this to be a statistically significant study. However, it yielded valuable insights on items such as the time of year when most problems occurred, and whether the frequency of incidents has been increasing. The number of deaths we

identified was about half those listed in Statistics Canada figures. We think therefore that we identified approximately 50% of the hazardous situations that occurred.

8.2.4 Guidelines for Ventilation

CMHC has been considering the problem of guidelines for ventilation. The great range in air-tightness of housing makes generalizations about controlled ventilation very difficult. A survey of air-tightness of houses across Canada was conducted under the auspices of the Saskatchewan Research Council with funding support from Energy Mines and Resources Canada. Two hundred houses were tested using the CGSB fan-door depressurization technique and substantial regional variations were found. It would be easier to establish guidelines on a provincial basis, especially considering that the moisture in the atmosphere varies markedly from region to region. It must be born in mind that this survey measured air-tightness under test conditions and the results do not necessarily correspond directly to the actual air change rate.

8.2.5 Backdrafting

CMHC is investigating backdrafting of heating appliances. Evidence of backdrafting is sometimes visible on combustion applicances. For instance, soot may be deposited on the combustion appliance, which would indicate that not all the products of combustion are going up the flue. Problems have been identified

with certain types of external chimneys. It has been found that conversion from oil to gas may lead to accelerated deterioration of chimneys.

Experiments have shown that even a considerable backdraft will not normally result in a carbon monoxide build-up. Blocked chimneys usually represent the most hazardous situation. Causes of backdrafting include built-in vacuum systems and indoor barbecue fans which are very powerful exhausts, capable in some circumstances of counteracting the usual venting action of chimneys.

We have attempted to develop a procedure that would enable us to identify in advance whether a hazardous situation exists for a particular home. A checklist was developed to see whether a simple but workable procedure could be set up to screen houses. The first stage involved testing 39 houses to assess the strengths and weaknesses of the check list. The sample was expanded to 100 houses after the initial testing and revision of the checklist. The tests included checking for backdrafts and for heat exchanger cracks.

We are also examining the use of a temperature sensor, on the furnace air intake, which could trigger an alarm if an extended reverse flow occurred.

We have also developed a computer program to simulate the performance of combustion appliances and flues. It is possible to examine features such as the thermal mass of a chimney, the insulation value of the chimney (to compare inside and outside chim-

neys), the frequency of operation of the furnace, and the potential for backdrafting. The program also makes it possible to examine the effects of appliances such as built-in vacuum systems and barbecues.

The Project Implementation Division is now outfitting a test house with various types of chimneys which are instrumented so that the model can be validated and further developed.

8.2.6 Moisture Survey

Another research initiative has been the assessment of sources of moisture in housing. Air enters houses on an uncontrolled basis. One of the entry routes is basements, the moisture coming from soil and through cracks in foundations. Our moisture studies have found very large amounts of moisture laden air are entering houses. One study found the total moisture load on a house to be 250kg water per day. This was far beyond what we expected to find.

8.2.7 Conclusion

I would suggest that an approach to controlled ventilation would be to exchange air on the basis of the quality of the air in the house, as measured by detectors. I see research into devices which enable us to control the pressure within houses.

8.3 Russell Questions

Mayhew: I think that controlling supply by pressure and exhaust by air quality is a good concept. I think there is a problem with the building code. Something is being put into the code without guidelines for the installation of the equipment that would be required. The improper installation of such equipment (e.g. an imbalanced exhaust) could result in backdrafting problems. In the R2ØØØ Program we are now going to induced draft or better furnaces in order to eliminate backdrafting problems. I think we need guidelines for retrofitting of existing housing to ensure that correct pressure balances are maintained.

Russell: The code is calling for an installed capacity rather than a requirement that it be used on a continuous basis. I think that, from an air quality standpoint, the half air change per hour is supportable. In Ontario, induced draft appliances are required to ensure that backdrafting does not occur in air-tight homes (R2ØØØ). This is a problem in the case of water heating appliances. There is currently only one Canadian built gas water heater that has CGA approval and which uses an induced draft system.

8.4 CMHC Field Research (Lorne Finlay)

Our group at CMHC is called the Project Implementation Division. We attempt to translate into practice the findings of the research group that Peter Russell is involved with.

8.4.1 Chimney Studies

We are currently testing various chimney conditions in a test house in Ottawa which has four different chimney types. These include the original chimney, an exterior masonry chimney, an interior metal insulted chimney, and an exterior metal insulated chimney. We are examining conditions under which reverse flow occurs in chimneys. We are trying to determine how fast those chimneys cool off, how quickly the combustion products can flow back into the house, and other information. The chimneys are instrumented with pressure taps and thermocouples. Depressurizing fans with variable speed controls are mounted in a doorway of the house and used to make the chimneys backdraft. This is being done to calibrate the computer model developed under the auspices of the research division.

8.4.2 Moisture Studies

In the Maritimes we have been carrying out field work for three years on ventilation solutions for moisture build-up and resulting structural deterioration in housing. We are studying houses that were built 17 years ago in which substantial rot of the structure has occurred. We have found similar problems in houses less than 5 years old. Sheeting materials have been preventing moisture from moving out of the wall on the cold (exterior) side. The wall systems have been modified and sensors left in the walls so that the presence of moisture could be monitored. We are also examining extruded polystyrene because of potential moisture problems in using it as an exterior sheeting to reduce heat loss.

In some houses in the Maritimes interior moisture build-up has been severe enough to lead to extensive growth of mold on interior surfaces. These houses are electrically heated with baseboard units and so do not benefit from the ventialtion provided by forced air heating systems. We are testing venting systems to determine whether the problem can be resolved. It has been found that by placing a vent high on a wall on the second floor, the interior relative humidity can be reduced from about 60-70% to about 30%. This is sufficient to eliminate the growth of mold. Another solution we are looking at is powered ventilation fans.

Some recent research work has shown that basements are a greater contributor to household humidity than was formerly perceived.

8.5 Finlay Questions

W. Patterson: Can the air seal for a house be as effective when placed on the outside of the envelope rather than on the inside of the envelope, the latter being the currently recommended practice?

Finlay: There is considerable disagreement about this. Vapour barriers were originally introduced to combat vapour diffusion. Only in the past 7 or 8 years has it been recognized that air leakage is much more important than vapour diffusion as a cause of moisture deposition in walls. If leakage is the problem, it does not matter whether air flow is prevented at the inside plane of the wall or the outside plane of the wall.

Russell: A company has built an experimental home in the Toronto area which is sealed at the exterior plane. The house is designed with a heating/ventilation system that keeps it slightly depressurized.

Finlay: The problem is keeping the construction industry properly trained. It took quite a while to convey the notion of the sealed vapour barrier. Introducing further changes in technology must be handled with care. I personally feel that it is easiest to provide a good seal at the inside plane of the envelope.

I should say in summary that it is very important to view the house as a system. There has been a tendency to consider each piece of equipment in isolation - for instance fresh air fireplaces which have an independent air supply; under certain

circumstances, they can backdraft and start fires. This shows the importance of considering other components of the house in evaluating the performance of any particular component.

9. SPECIALIZED INSTRUMENTATION FOR AIR QUALITY INVESTIGATIONS

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In 1979 we became involved in indoor air quality work because of the expertise we had acquired in analyzing the composition of air in the course of our work on outdoor air pollution. We discovered that people investigating indoor air quality were analyzing the criteria pollutants. These are the ones that are measured outdoors. They include sulphur dioxide, nitrogen oxides, total hydrocarbons, ozone and carbon monoxide. Where concentrations of these substances were measured in buildings, it was typically found that they did not exceed standards or guidelines. It was concluded that there was not a problem, but people were still complaining.

We found that gasses emitted by cleaners did not fall within the criteria pollutants. We therefore decided to examine trace organics - compounds like chloroform, carbon tetrachloride, methyl chlorides, vinyl chlorides. The problem is that there are no automated procedures for measuring the concentrations of these compounds. We will discuss the methods we have used to identify these trace organics in the workplace.

9.1 Airborne Substances

Airborne substances include both gasses, which exist as individual atoms or molecules mixed in with air, and particles, which are suspended in air. Gasses include both organic and inorganic substances. They remain in air until they are either absorbed by materials, or react to form other compounds, or condense as droplets. Particulates are solid and liquid substances scattered in the air. Each particle is usually composed of a group of molecules. They may be organics or inorganics or mixed. They may be dormant or living organisms. They vary greatly in size, shape and composition.

Organic compounds are receiving increasing attention. There are a very great number of organic compounds. They contain carbon as their primary constituent. In combination with hydrogen they form what we know as hydrocarbons. They can also contain nitrogen, oxygen, sulphur and other elements as secondary constituents. The same constituents may combine in many different ways with very different properties. They can be produced by biogenic and anthropogenic (both natural and human) activities.

Building products vary widely in chemical composition. This is true even of single categories of materials such as carpetting or caulking compounds. Numerous organic compounds have been detected as off-gassing from building materials. There are three main effects of these compounds - odours, irritations and carcinogenicity. The list in Table 9.1 (on page 125) shows simple hydrocarbons only. Other substances that may be detected in air

Table 9.1. Organic substances found in air.

Substance	OSHA Permissible Exposure Limit, ppm
Hydrocarbons:	
n-Hexane	500
n-Heptane	500
n-Octane	500
n-Nonane	--
n-Undecane	--
2-Methylpentane	--
3-Methylpentane	--
2,5-Dimethylheptane	--
Methylcyclopentane	--
Ethylcyclohexane	--
Methylcyclohexane	500
Pentamethylheptane	--
Aromatics:	
Benzene	1
Xylenes	100
Toluene	200
Halogenated hydrocarbons:	
Trichloroethane	350
Trichloroethylene	100
Tetrachloroethylene	100
Miscellaneous:	
Hexanal	--
Methylethylketone	200

include:

(i) oxygenated compounds such as ketones, alcohols, esters,

(ii) aldehydes, and

(iii) hydrocarbon combinations with chlorine, nitrogen, and sulphur.

9.2 Sampling Varying Concentrations of Organics

Odour thresholds occur over a very wide variety of concentrations, ranging from less than 0.001 ppm to 21 ppm. In order to identify compounds that may be causing odours in the indoor environment analytic techniques are required that are sensitive over this extremely wide range of concentrations and that will not fail to identify any of the substances.

The problem of analysis involves detecting the presence of compounds in the air, and their concentrations. There is not a single monitor that can perform comprehensive detection. There are a lot of single compound monitors. These are satisfactory when it is clear what one wishes to detect. However, comprehensive testing requires a very extensive set of sophisticated and expensive equipment. Passive monitors work on the principle of diffusion and permeation. They are analyzed in labs after exposure. They can be obtained for a variety of substances, for instance, vinyl chloride and phosgenes. The problem is that different compounds are absorbed at different rates.

Another way of sampling is to collect air in containers. One of the better systems is to collect air in a cartridge, drawing it

through an absorbent such as Tenax. A pump is used to pull air through an absorption tube with an absorber in it. Tubes are sometimes collected in tandem with different absorbers to collect a broader range of substances. An orifice is used to control the flow of air; a mechanism is required to measure the volume of air drawn through the sampler.

We find Tenax to be a very versatile and efficient collector for organic compounds. Many factors must be considered in collection procedures involving absorbents. Efficiency is a factor. If too much air is sampled, the tube capacity may be lost at the other end of the collector. Variable capacity is required or one will obtain too much of some organics and not not enough of others. The trap configuration is secondary in importance to using the correct sampling volume. Packing of the sampling tube must be arranged in order not to have channels which allow the air stream to bypass the absorber. Collection rates must be considered in order to obtain the desired range of instantaneous versus long term concentrations.

9.2.1 Removal of Sample Materials from the Trap

One recovery procedure used by us is a thermal desorption recovery from the absorbents themselves. A wide range of materials can be removed and it is possible to get a range from volatile to less volatile depending on time and duration of heating. Tenax is very stable; it can be heated to 300 degrees Celsius without decomposing. To be able to measure the amount of substances by gas chromatography, small volumes of material must be

obtained from the absorbent.

9.2.2 Identification of Organic Substances

The number of gasses that come off at a similar temperature can make it very difficult to identify them. There are some compounds for which one isomer out of half a dozen may be toxic. Then one is faced with identifying this one particular isomer.

We now have a large library of spectra which enables us to identify characteristics of substances generated by the mass spectrometer. We have a library of about 38,000 compounds.

To conclude, it is certainly simpler to use a specific monitor to ascertain levels of a known airborne substance. However, when looking for a wide range of substances, a wide range of concentrations, or for unidentified substances, the method I have described is necessary.

9.3 Questions

Farkas: First, I would like to make a comment, and then to ask a question. Even ascertaining the concentration of a particular substance, as opposed to surveying the range of substances present, can require the use of more sophisticated methods and instrumentation. In the case of organic volatiles, the interferences are so great and the specificity so poor that, especially at low levels, sampling for a single substance with a specific direct reading monitor is not possible unless the mixture of contaminants is fairly simple. The only direct reading instrument I

know of that can monitor a specific organic in a mixture of compounds is the infrared analyzer. Even this instrument has limitations.

Why use Tenax rather than, for example, charcoal?

Strosher: Tenax tubes have traditionally been used in hygiene to measure lighter fraction organic volatiles, while charcoal has been used for higher molecular weight solvents, and normally at higher concentrations (ppm). Detection at ppb concentrations is possible with a longer sampling period.

Charcoal is a very good absorbent if one is not testing for volatile materials. Instead of thermally desorbing, the materials can be removed with a solvent. It provides a very high efficiency of collection. However, lighter compounds may not collect very well on charcoal and thermally desorbing them is very difficult. It is not possible to heat charcoal enough to drive off the collected material.

Farkas: Is polarity part of the problem?

Strosher: To a certain degree, polarity is involved, although even hydrocarbons, which are not very polar, are sometimes difficult to take off the charcoal. The key factor is the absorptive capacity of the charcoal.

If one is only looking for higher molecular weight materials, charcoal can be used advantageously, but Tenax is more useful testing for a wider range. Certainly when a solvent can be used

to remove material from a filter, as is the case with charcoal, it is much easier to handle. The concentration of the material can be varied by changing the dilution of the solvent.

When sampling air and desorbing organics, it is usually necessary to guess how much of a material is on the filter. This necessitates taking 3 to 5 samples in order to get the proper range for all the quantities of materials. This is because when thermally desorbing, all sampled materials go off the absorbent into the analyzer.

Farkas: What concentrations of these materials (toluene, decane, benzene etc.) are you finding in a typical office setting?

Strosher: Each individual compound typically occurs below the levels that are set out by hygiene standards - ppb and ppt levels - ppm if there is carelessness, for instance in handling of cleaning solvents.

Most of the indoor work we have done to this point has been of a developmental nature. We have not been trying to establish whether the amounts of materials we are finding are good or bad.

Patterson: Can viruses and bacteria be detected by GC mass spec?

Strosher: We have never tried to do this.

Farkas: There is a methodology for microbiological sampling. There is a profession of industrial hygiene, to which I belong, that makes a specialty of measuring air quality in work environments. That is a very specialized field.

Kayser: I might mention that when measuring in these very small concentrations it is necessary to have standard samples for the basis of comparison which are of similar concentration.

Strosher: As part of our work, we have examined calibration techniques. The standards are, in some cases, very difficult to find. There are more and more being produced in apparati such as permeation devices. One hopes that certified standards, obtained in cylinders, are accurate. In many cases we have found that certified standards were either very inaccurate or not even present in the container they were supposed to have been sent in.

Love: What does a mass spectrometer cost?

Strosher: About $500,000 for a suitably sophisticated device. If particular substances can be identified by mass spectrometry, it is then possible to make further identifications by gas chromatography. This device would cost about 20 to 25 thousand dollars for a computerized system. Once identifications are done, they can be equated to gas chromatograph readouts. However, if one is not really sure what the substances are, a mass spectrometer is needed to identify them.

Question: Have you looked at particle sampling as opposed to gas sampling?

Strosher: When only looking for vapours, we use filters to keep particulates out of the sample. However, particles can be collected and identified with the mass spectrometer. It is also possible to separate vapours and particulates, and to determine

concentrations of each.

Question: Do you have equipment that does just particle sampling?

Strosher: Yes, though we have not done it within a building.

Question: How far are we from the point where air quality testing of buildings can be provided as a practical service?

Strosher: Hygienists would examine specific constituents rather than offering more comprehensive evaluations.

Farkas: I would argue that industrial hygienists do undertake comprehensive evaluations. However, the paucity of toxicological information and the complexities of data collection in the field make it difficult to assess environments in terms of health risk due to contamination of air.

There are techniques for assessing air quality. However, the situation becomes much more complicated if the investigation involves an unknown culprit. That is where the experimental work and powerful techniques being employed by Dr. Legge and Mr. Strosher become very important.

The problem is not simply in measuring substances in the air, but really in assessing what the health impact of that concentration of a substance might be, singly, or in combination with other substances. The criteria used in industrial environments are based on certain assumptions, and hence they cannot simply be transferred to other environments such as the home or office. I think then, the answer to the question about the practical

availability of air quality testing is both yes and no.

1Ø. A BENCHMARK STUDY OF A 'HEALTHY' OFFICE BUILDING

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1Ø.1 Preamble

Indoor air pollution is certainly not a new problem, but it warrants greater attention than it has received in the past. We spend more time indoors than did our ancestors. Consequently, even if concentrations of pollutants are low, time-weighted exposures become important. In addition, modern buildings are so constructed that uncontrolled air changes are far less than they once were. This may lead to increased pollutant levels indoors. Also, the number of people employed in commercial buildings is steadily increasing, and the profile of the workforce is changing. Many pregnant women continue working through their pregnancy. There are more older workers (the average age of our society is increasing), more individuals with chronic health problems and/or allergies, more handicapped employees, and so on.

The degree to which indoor air pollution represents a public health hazard has not been established. However, there is more and more evidence that it does adversely affect certain individuals, and that it causes, directly or in combination with other factors, much dissatisfaction among workers. This can have very significant economic consequences if it leads to increased absenteeism and/or decreased productivity.

Much new office construction consists of large hermetically sealed complexes. Temperature, humidity, air circulation and air change are controlled through elaborate systems of ducts and plenums. The interior is artificially lighted at constant levels with fluorescent lights that also generate heat. The machinery is controlled from remote control centres equipped with monitors, sensors, and computers. Interior partitions are painted and sprayed with chemicals to inhibit fungi, molds, and aging of paint. Offices are fitted out with long-life synthetic carpeting and furnishings, often sprayed with fire retardants. Plants, used extensively in "open landscape" interiors, are regularly fertilized and treated with insecticides. The buildings are cleaned with a variety of chemical products. There is generally considerable office equipment, some of which generate organic vapours (e.g photocopiers).

Then there are people. Assorted employee generated modifications, such as the fashioning of partitions, the closing of air outlets, and adjustment of thermostats are frequently in direct opposition to the original design. Employees smoke and create odours. Cleaning teams using noisy vacuum cleaners frequently work during office hours. Add the occasional error in the operation of the controls or the malfunction of components, and we begin to see how complex and precarious the life of the building becomes. Professional and popular literature is full of tales of problems in buildings.

"Air pollution", in the perception of the public embraces more

than "elevated levels of chemical or biochemical substances", since these generally cannot be detected in small concentrations. It involves elements such as odours, "stuffiness", drafts, excessive cold or heat, and so on. It may also reflect cumulative dissatisfaction with the job and the workplace itself. Or perhaps I should say that this dissatisfaction, which seems to stem from the move to a service oriented economy where employees do not have the satisfaction of turning out a tangible product, can make people more sensitive to "air quality".

One, then, must keep in mind that when dealing with "sick building syndrome", we cannot abstract the problems from the occupants. No building is sick when unoccupied - when there are no people to be dissatisfied, ill or frustrated.

10.2 Introduction to the Case Study

The purposes of the study were:

(i) to establish a benchmark, a profile of an office complex with no substantial amount of reported employee dissatisfaction, and

(ii) to establish whether any link exists between sporadic employee complaints and "air quality" (measurable properties of air).

The building studied had the following characteristics:

(i) it was about 5 years old, with an open landscape interior that was being used as designed,

(ii) it was clean, well-maintained, uncrowded,

(iii) smoking was permitted and a large proportion of employees smoked,

(iv) little office equipment (e.g. photocopiers, video display terminals) was in use,

(v) large quantities of paper were involved in the employees work,

(vi) there was no basement or underground parking,

(vii) there was a loading dock at ground level, and

(viii) it was located outside the city, far from other buildings.

The study team decided to investigate:

(i) respirable particulates,

(ii) formaldehyde,

(iii) volatile organics,

(iv) radon,

(v) carbon dioxide and carbon monoxide,

(vi) air circulation and pollutant migration, and

(vii) bacteria.

A multidisciplinary investigation involving chemists, engineers, and psychologists was organized. The first stage was a "walk through" assessment of the building to determine whether problems could be detected by visual inspection by the investigators. As a chemist, I looked at types of materials used, patterns of smoking, use of chemical products, and so on. The tour revealed that the open landscape building was indeed being used as designed. The building was very clean and had a very low density of occupancy (occupants per unit floor area). It appeared that about 75 percent of the occupants smoked. There was very little office equipment in evidence. There was substantial paper processing

and storing.

More detailed investigations involved two weeks of on-site measurements. A follow-up study, conducted some months later, confirmed the results of the initial study.

10.3 Items Investigated

10.3.1 Particulates

Particulates are frequently categorized according to size as non-respirable, where the diameter is greater than or equal to 10 microns, and respirable, when smaller. Several studies have shown that time-averaged indoor concentrations of respirable particulates generally exceed outdoor levels. The indoor concentrations have ranged from 100 to 500 micrograms per cubic metre of air (mcg/m3).

Indoor air may contain aerosol particles, natural mineral particles, man-made mineral fibres, and organic fibres. Tobacco smoke is the major source of indoor respirable particles. The particulate matter (8% by weight) of mainstream tobacco smoke, consists of approximately 3,800 different compounds, the principal ingredients being tar, polynuclear aromatic hydrocarbons, and metals such as cadmium and lead.

10.3.1.1 Sampling Method

A Gravimetric sampling head was used with a Cyclone vortex. This device filters non-respirable particles so that only the smaller respirable dust passes on to the collection stage (0.8 microgram pore size).

10.3.1.2 Results

In the first series of tests, the results for the 25 sampling locations in the building ranged from zero detected to 661 mcg/m3. This greatly exceeded the standard of 120 mcg/m3 averaged over a 24 hour period. It was determined that moisture accumulation in the filters during sampling was increasing the weight of particles. Hydrophobic filters were adopted, and control filters, which did not collect particles, were used to assess moisture uptake during sampling. Levels remained as high as 150 to 200 mcg/m3.

It was suspected that the elevated particle concentrations were due to extensive paper handling in the affected areas. It was expected that the use of electronic data storage would resolve this problem in the long term. For the short term, it was recommended that ventilation rates be increased in the affected areas.

10.3.2 Formaldehyde

Formaldehyde is a pungent colourless gas. Its characteristic odour can be detected by most people at levels below 0.8 ppm. Formaldehyde is the chief synthetic component of phenolic melamine and of acetal and urea resins. The latter are present in some insulation materials (e.g. UFFI), particle board, plywood, textiles, and adhesives. Other products in which free formaldehyde may be present include various plastics, rubber, printing products, paper, latex paint, photographic supplies, fumigants, and dyes. Typically, indoor concentrations are greater than outdoor concentrations. Out-gassing of formaldehyde from plywood and particle board is proportional to temperature and inversely proportional to humidity. The half life of formaldehyde in the indoor environment is about 44 years. Concern over the potential carcinogenicity of formaldehyde, combined with its ubiquity in building and other materials, justified exhaustive testing for its presence.

10.3.2.1 Sampling Method

Formaldehyde is soluble in water. By passing air through water, it is possible to collect airborne formaldehyde. The water samples are then sent for analysis. The sampling apparatus is quite cumbersome and not suitable for routine sampling.

10.3.2.2 Results

Concentrations ranged from 11 to 34 ppb at the sampling sites. The ASHRAE standard for non-industrial indoor environments is 100 ppb.

10.3.3 Volatile Organic Compounds

The hypothesis has been advanced that organic contaminants originating from building materials, furnishings, cleaning products plant sprays, and photocopiers are contributing to poor air quality and hence to unexplained health complaints in buildings. These substances have been found in greater numbers and higher concentrations in the indoor environment than in the outdoor environment.

Most indoor contaminants fall into three categories:

(i) aliophatic hydrocarbons,

(ii) alkylated aromatic hydrocarbons, and

(iii) chlorinated hydrocarbons.

Other compounds such as ketones, aldehydes, and esters have also been detected. It should be noted that human beings emit bio-effluents such as acetone, butyne, and methyl and ethyl alcohol.

10.3.3.1 Sampling Methods

The method is discussed in detail in the Legge/Strosher presentation. The sampling method for trace organic compounds in air is based on the adsorption of volatile organic compounds onto a suitable solid support. Subsequently they are thermally desorbed into a capillary trap immersed in liquid nitrogen and are then analyzed using a gas chromatograph and mass spectrometer. Tenax-GC absorbent (biphenylphenylene oxide polymer) has been used with some success to trap organic compounds in automobile exhaust, ambient air, stack gasses, and the gas phase of cigarette smoke. At present, it appears to be the most versatile absorbent for a wide variety of volatile substances. However, this is a very complex technique.

Bendix personal sampling tubes were used to pump air through a Tenax tube. Flow rates for each pump with attached Tenax tube were measured but were found low, and difficult to control and maintain at constant levels.

The objective of our work was the identification of all the organic vapours that could be found in the test building.

10.3.3.2 Results

More than 80 organic substances were identified. The concentrations of some chemicals, including chloroform, pentane, and trimethyl, reached levels as high as about 12-35 ppb. This is similar to the results obtained in a study of individual exposure at two university campuses in the United States. These levels are far below the limits for non-industrial workplaces. The highest levels of volatile organic compounds were found in the microfilm processing area.

10.3.4 Carbon Dioxide

Carbon dioxide is a colourless and odourless gas. Together with nitrogen, oxygen, and argon it is a normal component of "clean" ambient air. While outdoor concentrations are usually about 400 ppm, indoor levels may be considerably higher. Concentrations exceeding 2000 ppm have been observed in houses studied in the United States. The principal sources of CO_2 are combustion and human metabolism.

Moderate concentrations of CO_2 (1000-5000 ppm) may cause headache and sleepiness. Long-term exposure to such concentrations may lead to disequilibrium in the acid-base balance in humans.

10.3.4.1 Sampling Methods

Both CO_2 and CO sampling and monitoring were carried out with a very sensitive Miran-1A infrared monitor. Samples were taken at air intakes and exhausts, as well as at numerous interior points.

10.3.4.2 Results

Levels ranged from 370 to 600 ppm. All were far below the ASHRAE limit of 2500 ppm. It was noted that levels increased from the beginning of the workday, reaching a peak between noon and 3 pm, and then declined. There was a definite variation in levels that was not always associated with the concentrations of occupants.

10.3.5 Carbon Monoxide

Carbon monoxide is a product of the incomplete combustion of fossil fuels. It is a colourless odourless gas. Indoor concentrations vary between 0.5 and 5 ppm. Concentrations of 1000 ppm CO in air can lead to death. Short term exposures to high levels can cause numerous neurological changes that may persist for weeks, or even years, after the subject has been removed from the contaminated area.

Concentrations as low as 2% of the hemoglobin-CO complex in blood may impair the mental performance of the person afflicted, probably due to interference with oxygen delivery to the brain. Those who smoke more than a pack of cigarettes a day and inhale the smoke may have a hemoglobin-CO level in the blood as high as 5 to 18% compared with 1 to 2% for non-smokers.

The major source of CO is automobile exhaust; thus indoor parking garages and loading docks are a potential source of CO pollution in buildings. Cigarette smoking and combustion appliances are principal indoor sources.

10.3.5.1 Results

The levels of CO in the loading dock area varied from 2.5 to 20 ppm. On average, the concentration remained around 5 ppm. The peak concentrations occurred with the arrival of delivery trucks.

The levels of CO were well within the acceptable range. However, it would be worth checking these levels in winter, when loading dock doors are closed after truck arrivals.

10.3.6 Radon

Radon-222, an inert, radioactive gas is a product of Uranium-238. It is the heaviest of the noble gasses, and is considerably more soluble in water than oxygen or nitrogen. Radon's half life is 3.8 days; its radioactive decay gives rise to three "daughters" which are all radioactive.

The major sources of radon are soil and rocks, ground water, the water supply, natural gas, and building materials such as concrete, brick, and stone. The danger with radon lies in the inhalation of the radioactive "daughters". Subsequent decays deliver destructive radiation directly to unprotected tissues.

10.3.6.1 Sampling Method

Measurements were carried out with a Pylon RM-3000 Radon Detector. In this method, a known volume of air is drawn through a Millipore 0.8 r filter paper, trapping the particulates bearing the radon daughters. The filter, with particulates attached, is then transferred into the Pylon detector, which measures and gives readings of the radiation emitted by radon daughters.

10.3.6.2 Results

The Atomic Energy Control Board standard is 0.05 working level (WL). The ASHRAE standard is 0.01 WL. Levels of radon found in the building's sprinkler room were above the ASHRAE standard, which is used by Health and Welfare Canada. It was suspected that the source of contamination was an open pipe projecting through the floor of the room. It was suggested that an exhaust fan be installed to prevent any radon build-up. Passive monitors were placed in this area to determine whether the radon levels would remain high over a long period of time (i.e. two months).

Overall levels were highest in the morning and would drop off through the day.

1Ø.3.7 Bacteriological Testing

Bacteria, yeast, and moulds compose a broad class of biological organisms commonly called fungi. Fungi live as parasites, feeding on other living organisms, or as saprophytes, feeding on dead matter.

Moulds, yeast, and some species of bacteria develop spores. Spores are exceptionally resistant to physical and chemical influence. There are only a few sporulating bacteria that cause disease in man. Among them, however, are virulent pathogenic bacteria responsible for anthrax, tetanus and botulism.

Fungi and bacterial spores occur naturally in soils, water and air. They are continually introduced into the indoor environment where, under appropriate conditions of moisture and temperature, they may proliferate.

Fungi can precipitate allergic reactions both in the respiratory tract and on the skin. In rare cases they can produce pulmonary infections similar to those caused by bacteria and viruses.

Infectious disease organisms may be introduced into a building by people, water, or air. Once in a building, viruses, bacteria, and airborne spores circulate from room to room, from floor to floor. Certain systems, such as cooling towers, evaporative condensors, and humidifiers, provide conditions which amplify the natural population of these organisms. Air handling and conditioning equipment may disseminate these organisms throughout a building. A substantial reduction in ventilation rates, elevated

temperature or humidity levels all contribute to increases in their concentration.

There is a large number of cases where outbreaks of illness and epidemics have been traced to ventilation and humidification systems. For example, an outbreak of measles in one school was traced to the ventilation system. The classic example is the 1976 epidemic of legionellosis at a Philadelphia convention.

There are no standards for indoor air concentrations of either mold or bacterial species.

10.3.7.1 Results

The results of the bacteriological testing were essentially negative. The fungi were common contaminants, mainly Scopularinpsis and Hormodendrum species. Thermophilic fungi were not detected.

All cultures for legionella were negative. However positive results were obtained for Legionnaires' pneumophilia serotypes 1-4, in samples collected from a couple of points in humidifiers.

10.3.8 Pollution Migration Tests

The decay and migration of propane and n-butane seeded in different parts of the building were monitored by Photovac gas chromatograph analyses of bag samples collected at various locations over a period of time. These gasses are inexpensive, readily available and easily detected; as well, they have about the same molecular weight as air and so should follow air circulation paths readily.

In the tests, tracer gases were released in selected "source" rooms. All ventilating systems were operated as usual, and air samples were taken periodically in selected "destination" rooms. The sprinkler room was one source room. Once spaces were identified that were receiving air from the sprinkler room, passive doscimeters were placed in these spaces to determine whether elevated radon levels resulted from air movement. In fact, it was found that radon levels were not building up in other parts of the building.

The loading dock was another selected source space, the concern being migration of carbon monoxide. One finding was that the closest offices were not receiving the greatest amounts of carbon monoxide.

10.3.9 Air Circulation Tests

The objective was to locate "dead" spots where air circulation was inadequate.

10.3.9.1 Method

Although smoke pencils and other methods were tried, the most effective tool was found to be balloons filled with helium. The balloons were weighted so that they would remain immobile in dead air. Observers would then mark the path of the balloon on floor plans of the building. The rate of movement was noted by timing the travel of the balloon.

10.3.9.2 Results

It was found that dead air pockets corresponded to areas where concentration of particulates, carbon dioxide, and other substances were relatively high.

10.4 Discussion

10.4.1 Results

The overall objectives of the study were to:

(i) determine the overall quality of air in what was thought to be a "healthy" building, and

(ii) identify problem areas and potential problem areas.

The tests for particulates, formaldehyde, volatile organics, and CO2 were carried out at 25 sample locations (selected in random fashion). Radon and CO were monitored in the pump and sprinkler rooms and the loading dock.

The air levels of formaldehyde, volatile organic substances, CO and CO2 were considerably lower than the Threshold Limit Values established by the American Conference of Governmental Industrial Hygienists (ACGIH). They were also less than one tenth of the Occupational Health and Safety Administration standards which are arbitrarily defined as ceiling values by ASHRAE. The levels of particulates and radon were generally somewhat higher and in a few locations approached the ASHRAE limit. It was the opinion of the investigators that much of the discomfort perceived by the employees could be due to tobacco smoke. The percentage of smokers employed in the building (50-75%) was about double that of

the population at large (30%). It was suggested that smoking and non-smoking areas be organized. The air circulation study, described below, provided a good basis for establishing such areas.

The analysis of questionnaires administered in the course of the investigation showed a strong relationship between the absence or presence of occupant complaints about stuffiness, poor air quality, odours, and so on, and measurements of airborne substances and rates of air movement. That is, dissatisfaction was greatest where concentrations of substances were highest and air circulation poorest. Hence, people were found to be very good detectors of uncomfortable conditions. In the "healthy" building that was studied, the complaints were of a minor nature.

10.4.2 <u>General</u>

Threshold Limit Values (TLVs) are defined as the concentrations of airborne substances to which nearly all workers may be repeatedly exposed day after day without adverse effects. However, ACGIH cautions that due to variations in individual susceptibility, a small percentage of workers may experience reactions to the substances at concentrations equal to or below the threshold limit: "a smaller percentage may be more seriously affected by aggravation of a pre-existing condition".

It must be kept in mind that TLVs were developed for use in industrial environments where the pollutants present are the result of industrial activity. In these settings, one generally

finds one, or at most a few, major contaminants. Also, under these circumstances, ventilation rates are usually high and occupancy low; thus, the occupants themselves do not contribute to the pollution problem. Where more than one contaminant is present, in industrial environments, AGCIH provides a formula for calculating a "mixed exposure".

In an office setting, occupancy is usually higher and ventilation rates lower. Under these conditions, cigarette smoke and emissions from office equipment and furniture become a concern. In effect, there are thousands of contaminants present in concentrations much below TLV or even ASHRAE standards. It is impossible to consider all contaminants and to calculate a combined exposure. However, it is quite possible that the combined effect of small quantities of many contaminants may trigger a reaction in susceptible individuals.

The acute outbreaks caused by chemical substances (e.g mercury poisoning) or biological agents (e.g.legionella epidemic) where high concentrations of contaminants are present and the symptoms are well-defined have been, in most cases, solved successfully. On the other hand, chronic building-associated epidemics are difficult to treat since the causes are obscure and the cure far from obvious. Frequently, after a battery of tests has been run and the levels of all contaminants are found to be low according to the standards, no obvious cause is discerned, no solution (apart perhaps from the suggestion to increase ventilation rates) is offered, and the building enters the ever increasing "problems

due to unknown causes" category (1). It is reasonable to assume that the synergistic effect of a large number of compounds present in very minute quantities may be responsible for such chronic complaints encountered in office buildings.

An important aspect of the "chronic building associated health complaints" is the sheer magnitude of the problem. A large percentage of today's workforce can be found in offices, and this number is expanding steadily (2). Within these numbers, the high-risk groups represent a large proportion of the population. More than 20% of the population belongs to identifiable high-risk groups due to existing health problems. When age, smoking, and nutrition are taken into account, the figure is greater than one third (3).

Apart from high risk groups, a certain number of individuals are exceptionally sensitive to a variety of chemical substances or biological agents (4). It has been suggested that persons prone to allergies are more susceptible to allergenic chemical sensitizers. Potentially 15-20% of the population could be affected this way (5).

The degree of overlap between the two risk groups is not presently known. However, such overlap could be responsible for a substantial segment of society being particularly susceptible to indoor environmental stressors.

In conclusion, a low-cost way of checking for contaminant build-up in buildings may be to use carbon dioxide as an indicator.

This gas can be monitored with relatively inexpensive and easily transported equipment. Balloons are a low-cost tool for assessing air movement. Group interviews are also a good way of assessing substances that cause obvious irritation or discomfort.

10.5 References

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11. PANEL DISCUSSION

Mr. Ralph Gienow, Chief, Facilities Maintenance, Public Works Canada
Dr. M. Kayser
Mr. J. Love
Dr. J. Markham
Mr. P. Russell
Mr. M. Strosher

Butler: Dr. Kayser, in your presentation, you spoke about the open landscape interior of the study building. What kinds of barriers to air movement would have been located in that area?

Kayser: The ceiling height was about 3 metres. The building contained normal office furnishings such as desks and chairs. There were a small number of screens with open bottoms. Since the furniture was relatively old, any substantial out-gassing would have occurred prior to our study.

Brown: Were the employees informed of the nature and progress of the study while it was underway?

Kayser: Yes, by members of the study team.

Cool: Was the mechanical system modified after you identified areas of poor air circulation?

Gienow: Yes, some very minor modifications were made. As Dr. Kayser pointed out this morning, even the poorest areas were really not that bad. Some rebalancing of the air handling system was carried out. We found that some of the air intakes for the building had not been constructed to be as large as had been

called for in the design; this was rectified. A simple questionnaire by the property manager suggests that the complaints have been resolved. We are going to re-examine the building in April, 1985.

Cool: Some of the techniques you have identified could be used in the commissioning process to balance air handling systems in the building. Do you think this could work?

Kayser: I am not an engineer and I am not sure exactly what is involved in balancing the systems, but I do think that it could be a useful means of testing systems at the time of start-up. Certainly, the use of balloons to check air movement is relatively inexpensive. I think that looking at air circulation and pollution migration could be valuable for purposes other than air quality. For instance it might suggest in case of a fire, how smoke would move in a building and thus help in planning evacuation patterns for the building.

Gienow: We also feel that this information would be useful at the design stage, so that we can avoid repeating problems in new buildings.

Miller: What are the problems stemming from the spraying of plants, now commonly placed in the building interiors, with herbicides and pesticides? Would radon from the soil used to hold these plants (sometimes in great quantities in atria) be a problem?

Markham: The variety of treatment chemicals is so great that I do

not think there is a single answer. We certainly should not use treatment chemicals of a volatile or organo-phosphorus style indoors. One would certainly want to determine the concentrations of airborne chemical substances that would result from such spraying.

I do not think radon would be a problem given the ratios of the volume of commercial buildings and the volume of ordinary plant soil material, although I have not quantified this. It would certainly be easy to check the soil with various detectors.

Yoshida: Fertilizers might be another problem, because some of them are alpha-emitting, although these would likely be minute.

Russell: The main concern with radon is in housing where the ratio of foundation (and hence exposure to radon bearing soil and groundwater) to superstructure is much greater than in commercial buildings.

Kayser: I have investigated some of the substances used to spray plants and was horrified to learn that in some instances, methyl orange is employed. I do think that when extensive spraying is taking place, the building should be purged by increasing the ventilation. This might best be handled by spraying at the beginning of a long weekend and purging throughout the weekend. Similarly, it would be a good idea to purge buildings immediately after construction when outgassing is normally at its greatest.

Patterson: Where was the radon concentration greatest?

Kayser: It was a corner of the building that was below ground level and was experiencing some seepage of groundwater. One solution would have been to eliminate the seepage, but it seemed simpler to ventilate the room.

Johnson: You mentioned in your discussion that legionella and certain other thermophilic organisms had been isolated. Could you tell us how they were found?

Kayser: We simply took samples from areas such as the humidifier and sent them to a laboratory for analysis. Being a chemist, I cannot tell you anything of the analytic techniques employed.

Johnson: What kind of samples were they?

Kayser: Water samples were procured following the instructions of biochemists. We also took swabs from the sides and other surfaces of the humidifiers and sealed and labelled them. Actually thermophilic organisms were not found, although there were some other fungi. Many bacteria types were discovered apart from legionella.

Johnson: Who suggests 10% of the TLV (threshold limit value) as a guideline?

Kayser: ASHRAE (American Society of Heating Refrigerating and Air- conditioning Engineers)

Love: Keep in mind that the 10% guideline does not have a rigourous basis.

Johnson: That is also true of the TLV.

Brown: I understand that the TLV is not currently used in Alberta.

Markham: The Threshold Limit Values are laid down by a voluntary organization in the United States, the American Conference of Governmental Industrial Hygienists. It has no legal status. The Alberta regulations that govern worker exposure are called occupational exposure levels. They are often based on TLV's but they may not coincide with them. This may occur if the government feels that a particular TLV is not applicable to Alberta industry in a particular case. In my work with the Northwest Territories Government, I have suggested a similar course. I do not think we should be hypnotized by TLV's; we must remember, for instance, that TLV's are based on 5 out of 7 days exposure for 8 hours per day. Buildings require different standards because the population differs from the industrial work force. I do think that TLV's should be seriously considered because they are often based on the best available evidence. One problem is that there is often very little information available to support the development of standards.

Brown: How is radon detected? What effects does it have in human beings?

Kayser: Grab sampling is used for instantaneous readings, the sample later being transferred into a Pylon radon detector. Passive doscimeters may also be exposed over a period of months.

The doscimeters include a film on which the products of radon breakdown will leave traces. Geiger counters are not very reliable since they only measure the instantaneous level.

The health problem is due to the inhalation of radioactive particles into the very sensitive area of the lungs. These particles are believed to be carcinogenic. The alpha particles are the chief culprit. Radon itself is not toxic, it is the products of radon decomposition that are the problem.

Russell: The Bureau of Radiation Hazards of the Department of Health and Welfare are going to be introducing a new type of radon detector which they believe will be more reliable than existing track etch systems. Dr. Roger Eaton is the contact for people who are interested in this system.

Musto: Has there been any activity in the courts to do with indoor air pollution?

Russell: There has been a considerable amount of litigation having to do with UFFI (urea formaldehyde foam insulation). There is currently a class action case in Quebec before the provincial courts. A group of UFFI homeowners are suing CMHC.

Love: An article in the January, 1985 issue of Architectural Forum called "Examining Sick Buildings" dealt with American concerns on this. Often, what might be called quasi-legal action may have as great an impact as litigation. For instance, the Calgary Herald of February 21, 1985 (page A3) reported a grievance in Toronto by a federal civil servant, alleging that

smoking by fellow workers was creating an unsafe workplace.

W. Patterson: A few years ago there were reports in the media of air quality problems at a federal government building in Hull, Quebec. Can any of the panelists tell me what has happened since these reports.

Russell: The building is called "Les Terrasses de la Chaudiere". A report has been published, and I presume it would be available from Public Works Canada. From a cursory review, I would say that the final findings were surprisingly inconclusive regarding the major problems, considering the effort put into the investigation.

Leckie: Is there a standard for tobacco smoke? How would it be tested given that there or 3 or 4 thousand chemicals emitted from a burning cigarette?

Markham: I think it will come, but it is hard to say what the indices will be, given the numbers of chemicals to be detected.

Kayser: It is also difficult to assess the particulate emissions from cigarettes because the particles decompose on the filters that are used to sample them.

Love: I think you will find that the only existing standard is the ASHRAE (American Society of Heating Refrigerating and Air-conditioning Engineers) ventilation standard. I believe that standard called for 2.4 litres per second for non-smoking areas and 14 litres per second for smoking areas. Even with the 600%

increase in ventilation for smoking, it was recognized that the air quality would still not be as good as in non-smoking areas with the lower ventilation rate.

Gienow: In our experience, smoking has not been so much of an air quality problem in open office areas. I know that the Department of National Defence, Transport Canada, and others have disallowed smoking in conference rooms because in enclosed spaces the air change is less than in open areas. Some departments have also changed regulations to set up separate smoking and non-smoking areas.

Leckie: Is there any inexpensive type of desk-top air cleaner that is effective in reducing tobacco products in the air.

Kayser: When operated incorrectly, these appliances become problems in themselves because they generate ozone.

Yoshida: I have had a chance to measure cigarette smoke in hospitals over the past two years. I measured airborne particulates and carbon dioxide. These particles range from 0.01 to 0.5 microns in diameter. These were captured with a diffusion battery, an instrument specially designed for visible particles.

We found a background level of 18 to 36 thousand particles per cubic metre, which is average to clean for hospitals; in smoking areas we found up to 360 thousand particles per cubic metre.

Edworthy: Are there any simple guidelines for assuring homeowners that air quality is satisfactory? For instance, can we say that

if humidity levels are kept under control air quality will be sufficient?

<u>Russell</u>: There are so many factors influencing indoor air quality that this is very difficult. These factors can range from the level of employment (which, for instance, has led to increased use of wood-fired heating systems in some parts of the country) to the age of the dwelling. One would also have to consider the habits of the occupants - for instance tobacco smoking, storage of paints or other materials indoors. One also has to consider that people vary in their tolerances to substances. Use of humidity level as a guideline may be better than no rule of thumb at all, but it is certainly subject to many reservations.

It would appear from humidity measurements in a small number of houses (14) that CMHC has investigated, that residential humidity generation is much greater than we had anticipated. This would suggest that if ventilation is adequate to control humidity, it will likely be adequate to control other air quality problems. However, this cannot be definitively stated to be true for every case.

<u>Edworthy</u>: You are saying, then, that we have to be reactive - that we have to respond to concerns on an individual basis rather than being able to prescribe solutions generically.

<u>Russell</u>: Yes. There is too much variability in the housing stock, the habits of the occupants, and their susceptibility.

<u>Edworthy</u>: This also calls into question the building code

establishing a norm of 0.5 air changes per hour as a safe standard.

Russell: I think that a measure to introduce 0.5 air changes per hour as a guideline, or as an accepted part of the building code, will prove to be an interim measure. Bearing in mind all of the variabilities involved, I think that it is the most reasonable step that can be taken at this time since it is something that people can readily understand and apply.

Edworthy: If that is an interim measure, what do you see happening in the future?

Russell: I will be very speculative. I think it is realistic to believe that we could do a good job of controlling the quality of the air if we could control the carbon dioxide level. Currently, carbon dioxide detectors for ventilation control are too expensive to be extensively used in residential settings. I think we will see such systems become economical enough for residential application. I would be surprised if by 1990 we do not see a revision to the building code that would include some such criteria for controlling air quality.

The National Research Council of Canada has carried out monitoring of carbon dioxide in a cinema and a school located in Ottawa. A company in Montreal currently produces a carbon dioxide detector for commercial buildings. I believe that the basic equipment costs about $6000.

N. Patterson: Is there a fluid that could be used to scrub out

most of the pollutants encountered in the indoor environment?

Russell: I cannot answer your question directly. The UFFI Centre operated by Consumer and Corporate Affairs (Canada) is currently experimenting with a scrubber to remove formaldehyde from air. National Research Council of Canada and Lawrence Berkeley Laboratories (USA) have also been examining wet scrubbing of formaldehyde. A major problem at the residential level is the maintenance of the scrubber itself.

Heat recovery ventilation systems may offer an alternative way of improving indoor air quality without some of the problems inherent in scrubbing systems.

Patterson: Could not a scrubbing process be integrated with the humidification system?

Russell: The problem is that air-tight houses, which are more likely to have air quality problems, normally require dehumidification rather than humidification.

Gienow: We have spent a lot of time today discussing pollutants. I would like to point out that the majority of complaints my group respond to have to do with temperature, drafts, stuffiness. Complaints of headaches and other such symptoms tend to be far less common.

Edworthy: There is some perception that energy conservation and good air quality are conflicting goals. I would like to assert that they are complementary goals. Tightening up housing can

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